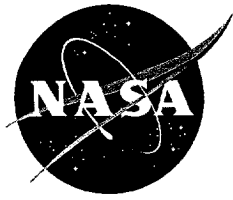


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Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle Mission STS-111

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June 2005

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7121 Standard Drive
Hanover, MD 21076-1320

**DEBRIS/ICE/TPS ASSESSMENT and
INTEGRATED PHOTOGRAPHIC ANALYSIS
OF SHUTTLE MISSION STS-111**

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DEBRIS/ICE/TPS ASSESSMENT
AND
INTEGRATED PHOTOGRAPHIC ANALYSIS
OF
SHUTTLE MISSION STS-111

June 5, 2002

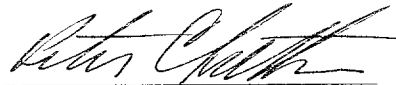
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FOREWORD

The Debris Team has developed and implemented measures to control damage from debris in the Shuttle operational environment and to make the control measures a part of routine launch flows. These measures include engineering surveillance during vehicle processing and closeout operations, facility and flight hardware inspections before and after launch, and photographic analysis of mission events.

Photographic analyses of mission imagery from launch, on-orbit, and landing provide significant data in verifying proper operation of systems and evaluating anomalies. In addition to the Kennedy Space Center Photo/Video Analysis, reports from Johnson Space Center and Marshall Space Flight Center are also included in this document to provide an integrated assessment of the mission.

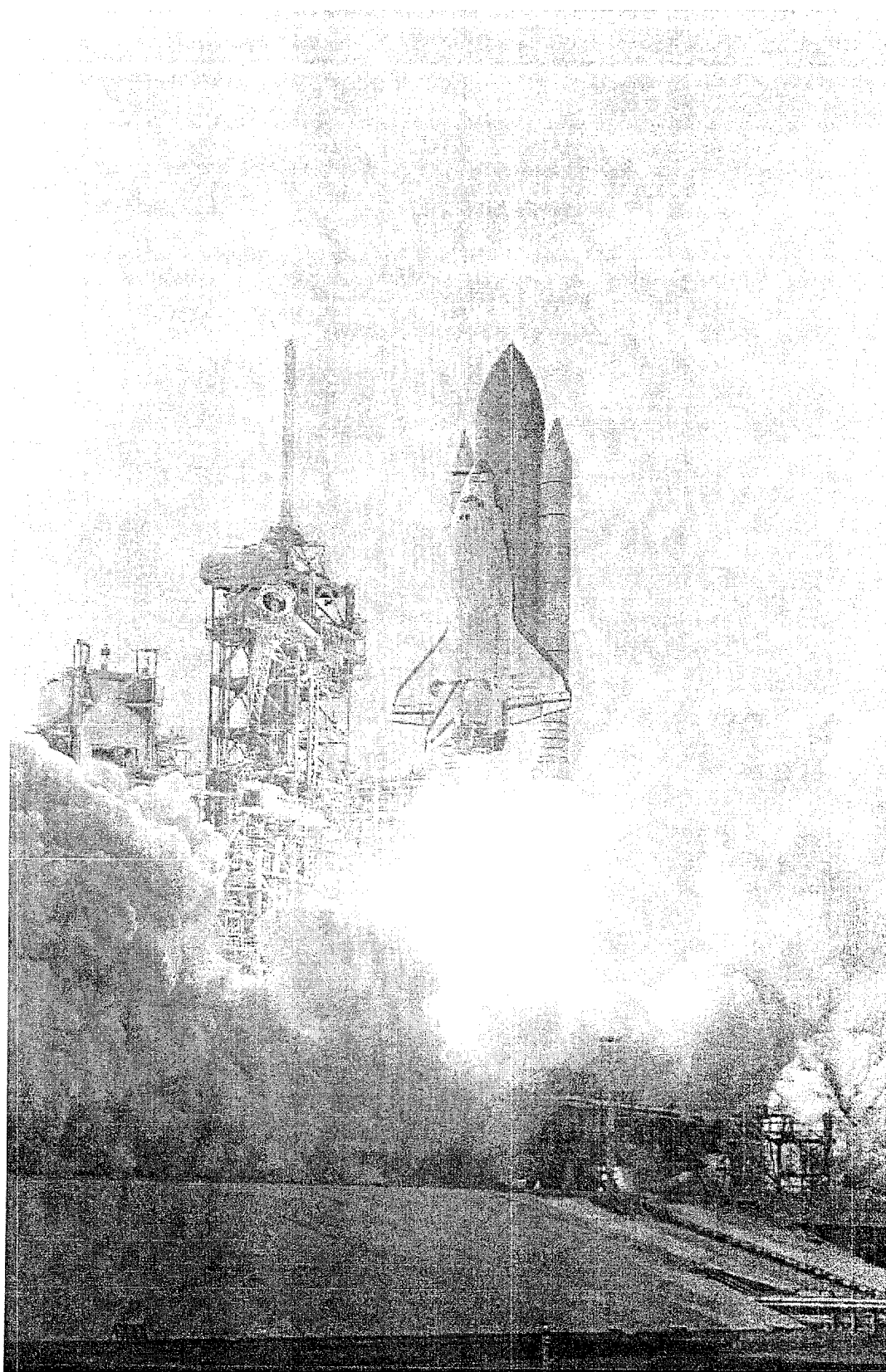


Photo 1: Launch of Shuttle Mission STS-111

1.0 SUMMARY OF SIGNIFICANT EVENTS

STS-111 consisted of OV-105 Endeavor (18th flight), ET-113, and BI-113 SRB's on MLP-1 and Pad 39A. Endeavour was launched at 5:22:49 pm EDT on 5 June 2002. Landing was at 1:57:41 pm local/eastern time on 12 June 2002 at Edwards Air Force Base in California.

Post landing inspection of Orbiter tiles showed a total of 79 hits, of which 26 had a major dimension of 1-inch or larger. The Orbiter lower surface sustained 47 total hits, of which 21 had a major dimension of 1-inch or larger, both numbers are within family. The area from the nose landing gear to the main landing gear wheel wells sustained 19 hits with 8 greater than 1-inch. Approximately 14 of the total lower surface hits were around the LH2 umbilical area. Most of these damage sites around the ET/ORB umbilical were most likely caused by pieces of the umbilical purge barrier flailing in the airstream and contacting tiles before pulling loose and falling aft.

In summary, both the total number of Orbiter TPS debris hits and the number of hits 1-inch or larger were somewhat less than the family average.

2.0 PRE-LAUNCH BRIEFING

The Debris/Ice/TPS and Photographic Analysis Team briefing for launch activities was conducted at 1500 on 4 June 2002. The following personnel participated in various team activities, assisted in the collection and evaluation of data, and contributed to reports contained in this document.

| | | |
|-------------|-------------|---------------------------------------|
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| S. Otto | LMMSS | ET Processing |
| M. Eastwood | Thiokol-LSS | SRM Processing |

2.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

The pre-launch inspection of the MLP-1, Pad A FSS and RSS was re-performed on 4 June 2002 from 1700 to 1900 hrs EDT.

Three facility items were documented in Appendix K of S0007VL4. They were:

- -Y ET access platform flip is in down position. This flip needs to be raised prior to RSS retract. The end of the platform is within 3.5 inches of the External Tank.
- Excessive sand/debris on MLP deck and in gutter around MLP zero level.
- Two missing handrails (S2-16 and P4-1) and one broken pip pin (handrail S4-16) from removable handrails around the SRB exhaust hole. The handrails were already removed and were situated on the MLP deck. Pip pins need to be accounted for.

All items were in-work at the conclusion of walkdown. The configuration of the ET access platform was being corrected and the missing pip pins on handrails were located or accounted for.

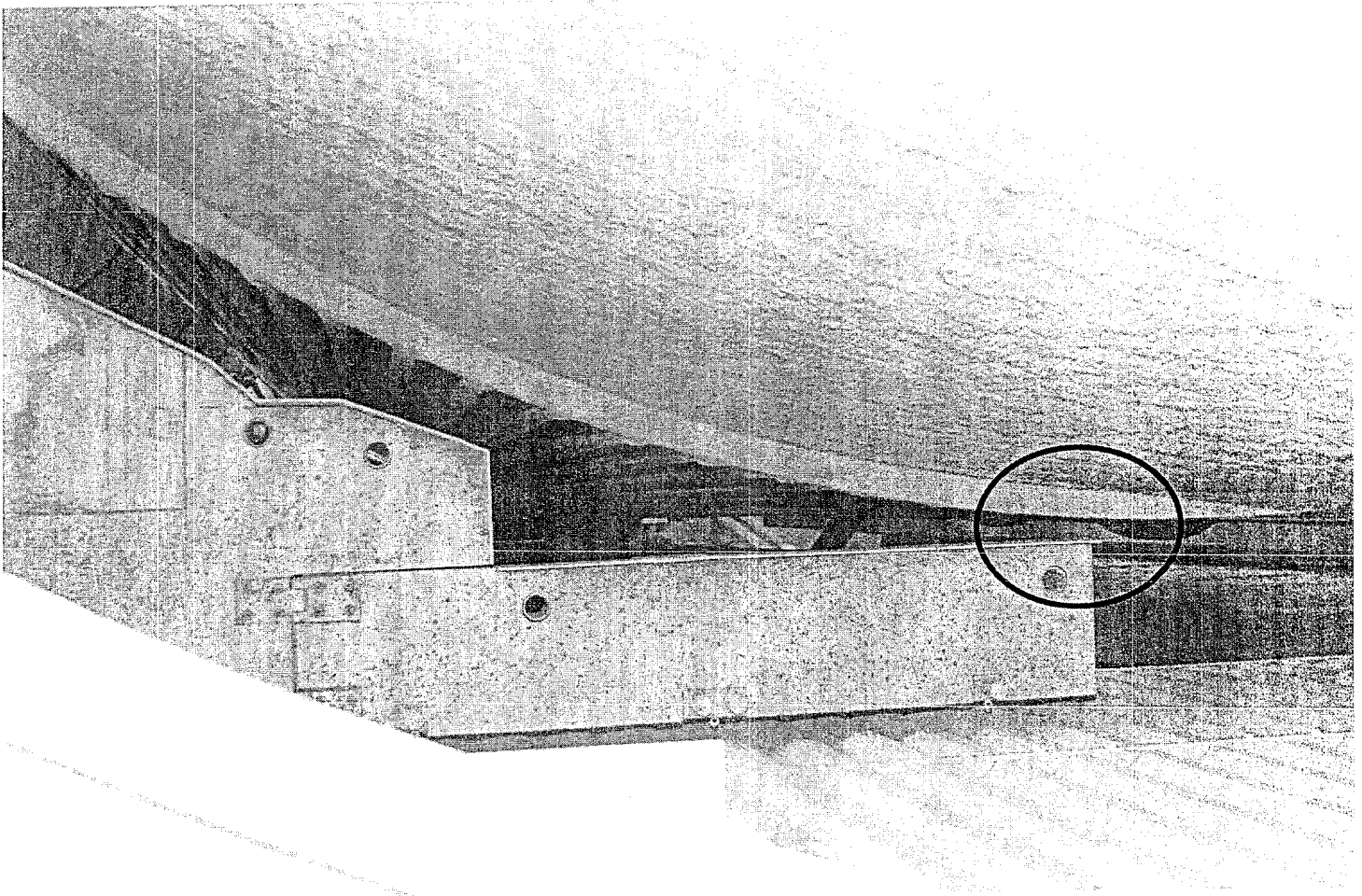


Photo 2: -Y ET access platform flip is in down position (out of configuration).
Clearance at closest point was less than 3.5 inches.

3.0 SCRUB

3.1 FINAL INSPECTION – Weather Scrub

The Final Inspection of the cryoloaded vehicle was performed from 1345 to 1515 hrs on 30 May 2002 during the two-hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria (LCC) or OMRS criteria violations. There was no acreage icing concerns. There was also no protuberance icing conditions outside of the established database.

A portable Shuttle Thermal Imager (STI) infrared scanning radiometer was utilized to obtain vehicle surface temperature measurements for an overall thermal assessment of the vehicle, particularly those areas not visible from remote fixed scanners, and to scan for unusual temperature gradients.

3.1.1 ORBITER

No Orbiter tile or RCC panel anomalies were observed. The RCS thruster paper covers were intact though the cover for thruster F1L was discolored. Ice/frost had formed all the way around the SSME #2 heat shield-to-nozzle interface and from the 3 to 9 o'clock position around the SSME #1 heat shield-to-nozzle interface.

3.1.2 SOLID ROCKET BOOSTERS

No SRB case, closeout, or protuberance anomalies were observed. SRB case temperatures measured by the STI radiometers were close to ambient temperatures, ranging from 70 to 78 degrees F. All measured temperatures were above the minimum requirement.

3.1.3 EXTERNAL TANK

The ice/frost prediction computer program 'SURFICE' was run as a comparison to infrared scanner point measurements. The program predicted temperatures above 32 degrees F throughout ET cryoload. The following table shows ambient condition, SURFICE prediction and IR surface temperatures at the start of FIT walkdown. The SURFICE Ice Prediction Program does not take into account the effect the sun has on the ET surface temperatures.

| Ambient conditions – 1400hrs | SURFICE Predictions | IR Surface Readings |
|------------------------------|-------------------------|--------------------------|
| 79 Degrees F. | LO2 ogive 70 Degrees F | LO2 Tank 65-80 Degrees F |
| 80% RH | LO2 barrel 65 Degrees F | |
| 9 knots | LH2 upper 65 Degrees F | LH2 Tank 64-80 Degrees F |
| 070 degrees | LH2 lower 70 Degrees F | |

The Final Inspection Team observed very light condensation on the LO2 tank acreage. No acreage ice/frost formations were observed. There were no TPS anomalies on the LO2 tank.

No significant anomalies were present in the intertank TPS. No cracks were detected in the intertank stringer valley TPS. Ice and frost accumulations on the GUCP were typical.

The LH2 tank was wet with light to moderate condensate. There were no acreage TPS anomalies. A small frost ball, approximately ½ inch diameter, had formed on the aft dome manhole cover at the +Z position. This condition is acceptable per NSTS-08303.

Typical amounts of ice/frost had accumulated in the LO2 feedline bellows and support brackets.

A 4 inch long and 1/4 inch wide stress relief crack was observed in the -Y vertical strut TPS with no offset. This condition has been observed on previous vehicles and found acceptable for flight per the NSTS-08303 criteria.

There were no TPS anomalies on the LO2 ET/ORB umbilical. Ice and frost in the LH2 recirculation line bellows and on both burst disks was typical. Likewise, a typical amount of ice/frost had accumulated on the LH2 ET/ORB umbilical purge barrier outboard side, inboard side, forward, and aft surfaces. Typical ice/frost fingers were present on the pyro canister and plate gap purge vents. No unusual vapors or cryogenic drips had appeared during tanking, stable replenish, and launch.

3.1.4 FACILITY

All SRB sound suppression water troughs were filled and properly configured for launch. No leaks were observed on the GUCP or the LO2 and LH2 Orbiter T-0 umbilicals.

3.2 T-3 HOURS TO SCRUB

After completion of the Final Inspection on the pad, surveillance continued from the Launch Control Center. Twenty-two remote-controlled television cameras and two infrared radiometers were utilized to perform scans of the vehicle. No anomalies were detected during this timeframe.

This attempt to launch STS-111 was scrubbed due to inclement weather in the launch area.

3.3 POST DRAIN INSPECTION

The post drain inspection of STS-111, MLP-1, and Pad A FSS was conducted on May 31, 2002 from 0050 to 0135 hours under dark conditions. Nevertheless, visibility was adequate for the inspection.

No MLP deck or facility anomalies were detected.

Likewise, no anomalies were observed on the SRB's.

Orbiter tiles, RCC panels, and SSME's were in nominal configuration. RCS thruster paper covers were intact.

The GOX vent hood was in the raised position extended over the ET. The post detank Pad inspection verified no anomalies on the ET nose cone. No topcoat was missing from the nose cone area under the GOX vent seal footprint.

The External Tank was in excellent condition. Bipod jack pad standoff closeouts were in nominal condition. All PDL repairs were intact with none protruding. No crushed foam or debris was detected in the LO2 feedline support brackets. The stress relief crack observed during the final inspection on the -Y vertical strut forward facing TPS was visible.

Less than normal amounts of ice were observed in the LO2/LH2 feedline bellows, the lower EB fittings, and on the ET/ORB umbilical purge vents due to condensate runoff and rainfall.

The three ET burst discs were monitored from the LCC Firing Room 2 via OTV and inspected from the MLP Zero Level and no anomaly was observed.

In summary, no IPR conditions and no flight hardware concerns were detected during the post drain inspection. There are no constraints for the next cryoload.

4.0 LAUNCH

4.1 PRE-LAUNCH SSV/PAD INSPECTION

The Post-Drain and additional T-8 hour inspection of the Pad and SSV performed as a result of the weather scrub satisfied the pre-launch inspection requirement. No new issues or concerns were detected.

4.2 FINAL INSPECTION

The Final Inspection of the cryoloaded vehicle was performed from 1130 to 1315 hrs on 5 June 2002 during the two-hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria (LCC) or OMRS criteria violations. There was no acreage icing concerns. There was also no protuberance icing conditions outside of the established database.

A portable Shuttle Thermal Imager (STI) infrared scanning radiometer was utilized to obtain vehicle surface temperature measurements for an overall thermal assessment of the vehicle, particularly those areas not visible from remote fixed scanners, and to scan for unusual temperature gradients.

4.2.1 ORBITER

No Orbiter tile or RCC panel anomalies were observed. The RCS thruster paper covers were intact though the cover for thruster F1L was slightly discolored. Ice/frost had formed all the way around the SSME #2 heat shield-to-nozzle interface and from the 3 to 9 o'clock position around the SSME #1 heat shield-to-nozzle interface.

4.2.2 SOLID ROCKET BOOSTERS

No SRB case, closeout, or protuberance anomalies were observed. SRB case temperatures measured by the STI radiometers were close to ambient temperatures, ranging from 68 to 78 degrees F. All measured temperatures were above the minimum requirement.

4.2.3 EXTERNAL TANK

The ice/frost prediction computer program 'SURFICE' was run as a comparison to infrared scanner point measurements. The program predicted temperatures above the 32 degrees F throughout ET cryoload. The following table shows ambient condition, SURFICE prediction and IR surface temperatures at the start of FIT walkdown. The SURFICE Ice Prediction Program does not take into account the effect the sun has on the ET surface temperatures.

| Ambient conditions – 1100hrs | SURFICE Predictions | IR Surface Readings |
|------------------------------|-------------------------|----------------------------|
| 82 Degrees F. | LO2 ogive 72 Degrees F | LO2 Tank 65 - 83 Degrees F |
| 79% RH | LO2 barrel 67 Degrees F | |
| 10 knots | LH2 upper 66 Degrees F | LH2 Tank 64 - 83 Degrees F |
| 094 degrees | LH2 lower 72 Degrees F | |

The Final Inspection Team observed very light condensation on the LO2 tank acreage. No acreage ice/frost formations were observed. There were no TPS anomalies.

No anomalies were present in the intertank TPS. No cracks were detected in the intertank stringer valley TPS. Frost spots were observed above fasteners in the -Z/-Y quadrant of the intertank valleys. This condition is acceptable per NSTS-08303. Ice and frost accumulations on the GUCP were typical.

The LH2 tank was wet with light condensate on the upper portion and a moderate amount of condensation at the aft end. There were no acreage TPS anomalies.

Typical amounts of ice/frost had accumulated in the LO2 feedline bellows and support brackets.

A 4 inch long and 1/4 inch wide stress relief crack was observed in the -Y vertical strut TPS with no offset. This condition has been observed on previous vehicles and found acceptable for flight per the NSTS-08303 criteria.

Two cracks were observed in the +Y longeron TPS closeout. The cracks also had 4 frost balls associated with them. IPR-111V-095 was generated since the condition is not covered in the NSTS-08303 Acceptance Criteria.

In the forward portion of the longeron closeout was a 12 inches long, with no measurable width (hairline), crack propagating diagonally aft. This crack had three frost spots associated with it. The second crack, located at the middle portion of the longeron closeout, was 12 inches long with no measurable width. This crack also propagated diagonally and had a frost ball at its aft end. Neither of the cracks followed knit lines or exhibited offset.

The cracks most likely resulted from a combination of typical thermal/mechanical induced TPS stresses and localized defects in the thick BX-250 closeout foam. An assessment was performed that consisted of two parts addressing the ET thermal/structural integrity for flight and possible debris threat to Orbiter lower surface tiles. With all the data taken, there was no evidence of debonds and the condition appeared to consist of shallow surface cracks only.

The thick metal (mass) of the longeron is a heat sink. Coupled with the cryogenic temperatures on the interior of the longeron, the structural temperature cannot increase significantly even in the event of foam loss. This precluded thermal/stress concerns for ascent and re-entry. Due to the relatively small, localized area compared to the overall ET size, there were no propellant quality issues even with material loss during launch.

Since the cracks exhibited no offset, foam adhesion to substrate and sidewall longeron ribs provide adequate strength, which would preclude large pieces of debris from coming loose. Only normal ablation would occur. Aero/thermal simulation data showed no foam loss when shallow cracks were present in the material. Therefore, there was no threat from TPS debris nor was there any concern about ice debris since frost, but no ice, had formed in association with the cracks.

Nevertheless, debris trajectory data was examined for possible impacts on Orbiter lower surface tiles. The database showed only possible impacts above Mach 2.5. At this speed there is low dynamic and any particles originating from this location will be of low energy resulting in minimal damage to Orbiter tiles.

In conclusion, the condition was accepted for flight by MR.

4.2.4 FACILITY

All SRB sound suppression water troughs were filled and properly configured for launch. No leaks were observed on the GUCP or the LO2 and LH2 Orbiter T-0 umbilicals.

4.3 T-3 HOURS TO LAUNCH

After completion of the Final Inspection on the pad, surveillance continued from the Launch Control Center. Twenty-two remote-controlled television cameras and two infrared radiometers were utilized to perform scans of the vehicle. No anomalies were detected during this timeframe.

STS-111 launched at 5:22:49 pm EDT on 5 June 2002.

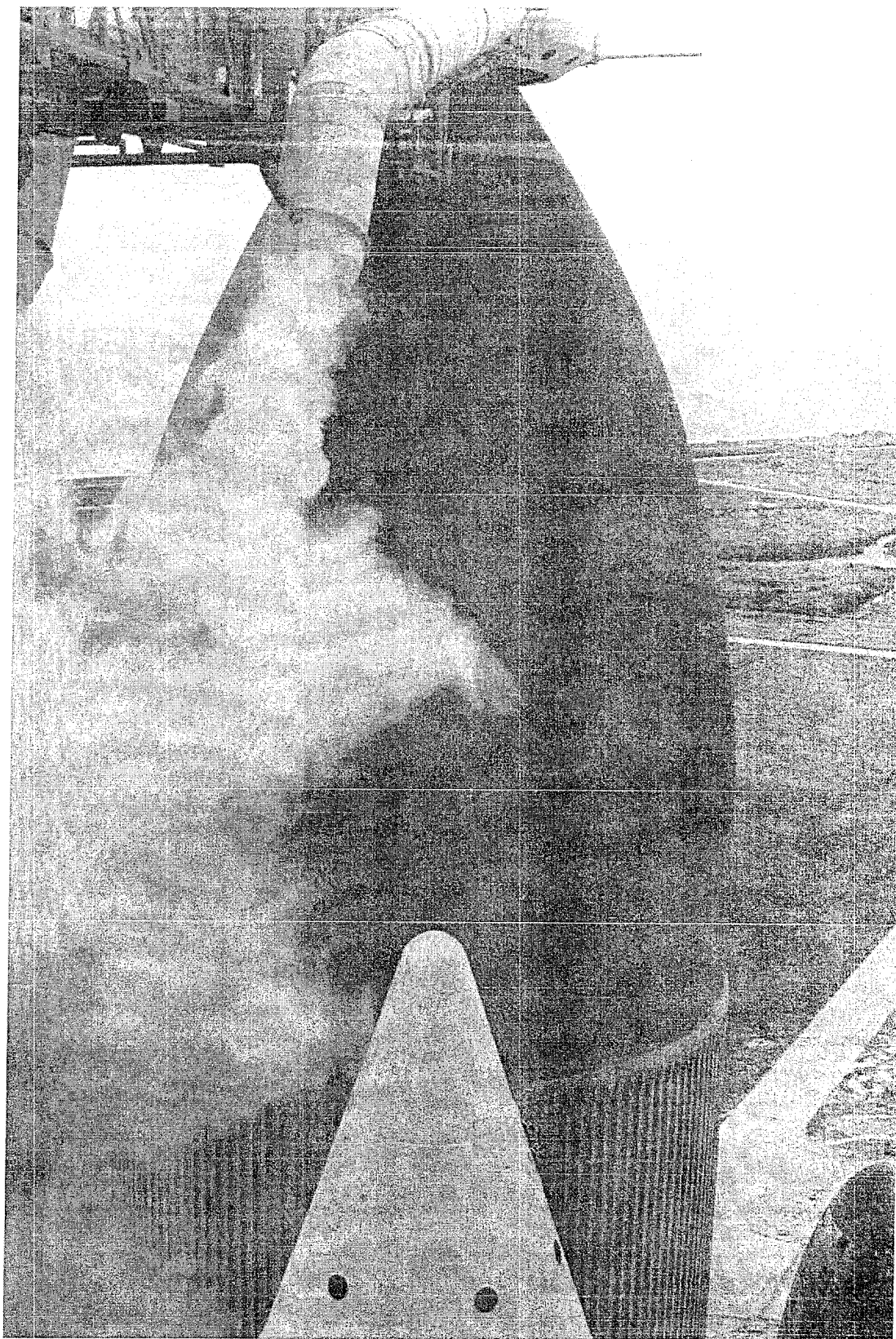


Photo 3: LO2 tank acreage.

Very little condensate was present on the LO2 tank acreage. Surface temperature ranged from 65 to 83 degrees Fahrenheit. There were no acreage TPS anomalies.

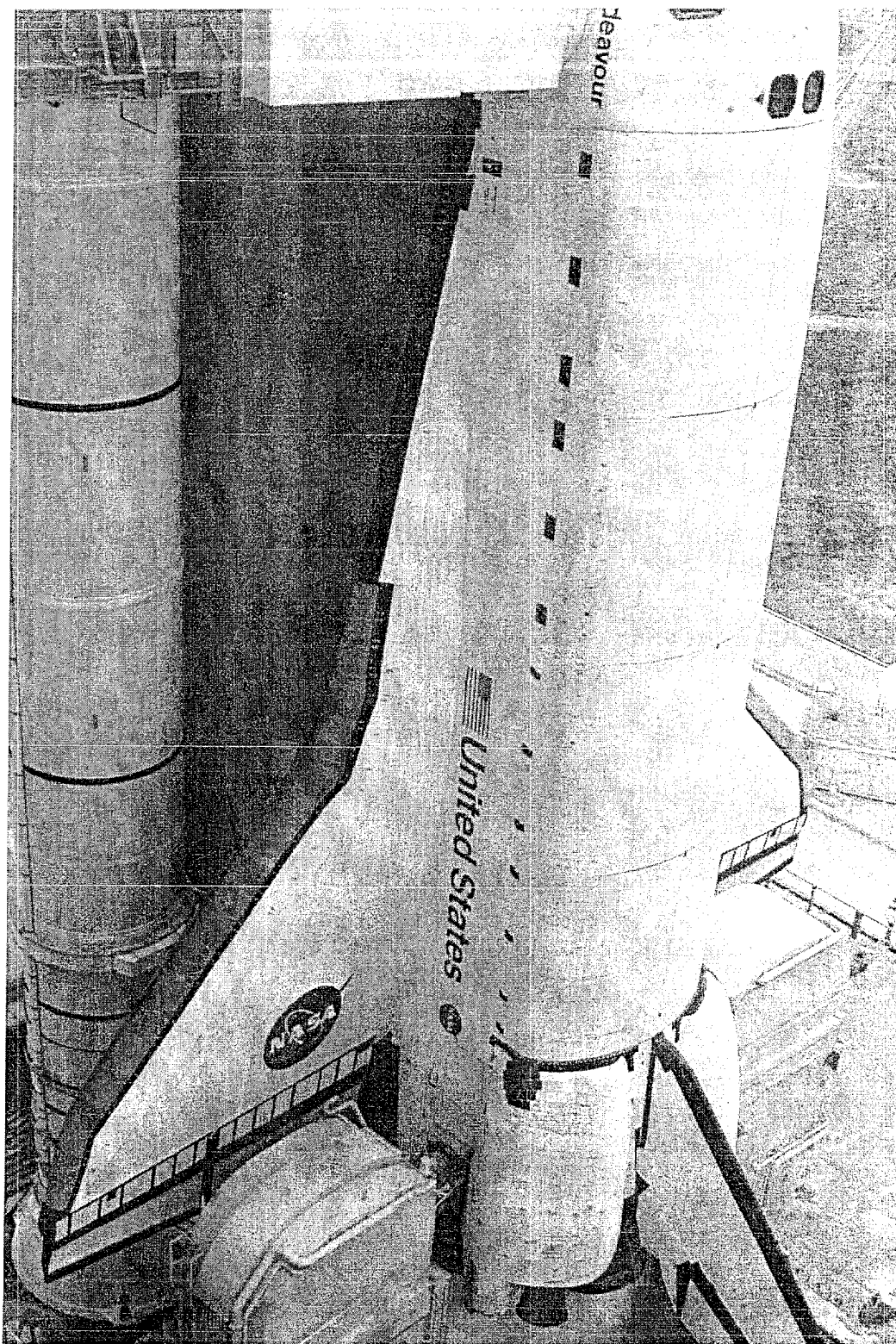


Photo 4: LH2 tank acreage.

The LH2 tank was wet with light condensate on the upper portion and moderate condensation at the aft end. Surface temperature ranged 64 to 83 degrees Fahrenheit. There were no acreage TPS anomalies.

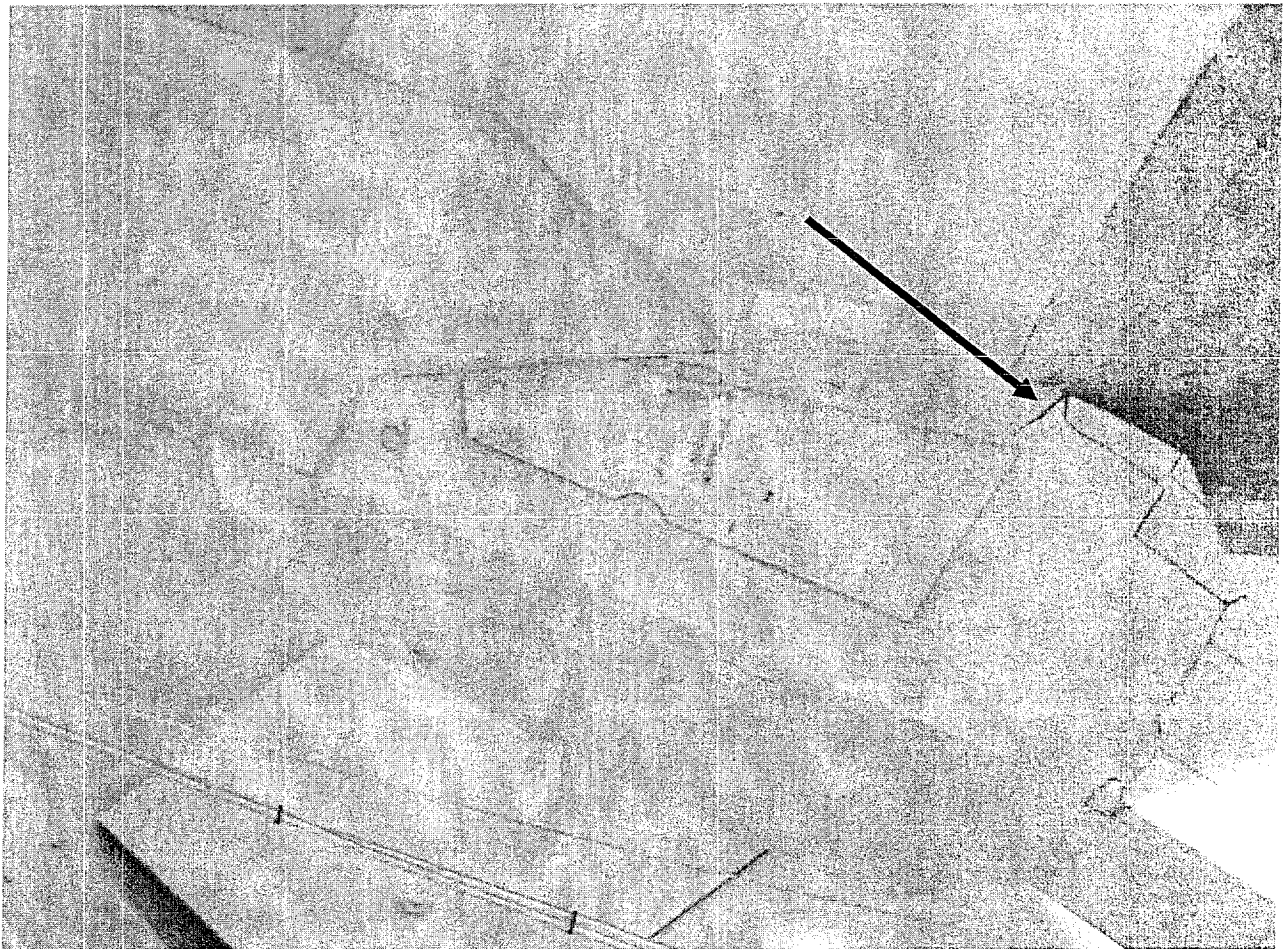


Photo 5: Crack in -Y Vertical Strut TPS

A 4 inch long and 1/4 inch wide stress relief crack was observed in the -Y vertical strut TPS with no offset. This condition has been observed on previous vehicles and found acceptable for flight per the NSTS-08303 criteria.

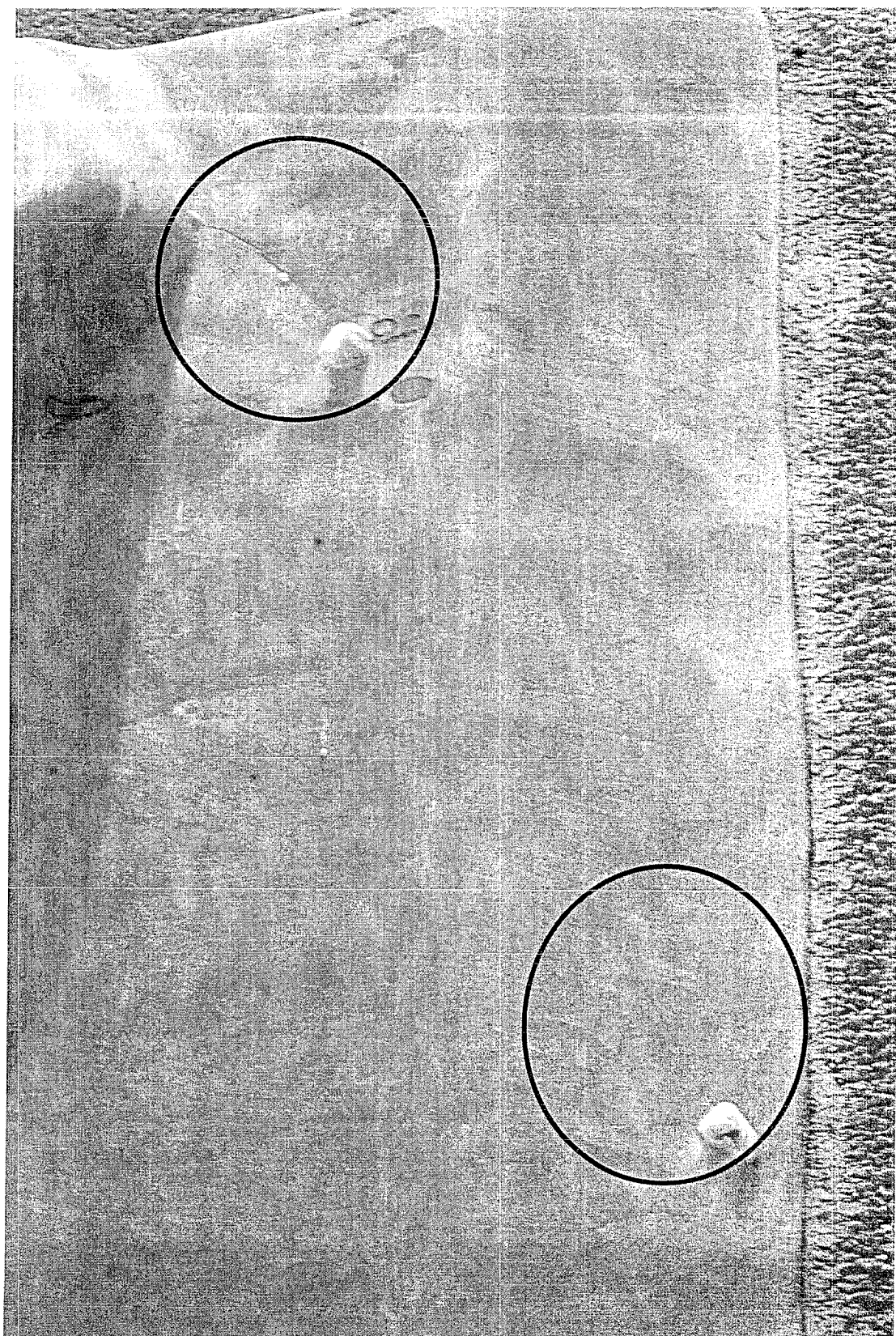


Photo 6: Cracks in +Y Longeron TPS closeout.

Two cracks were observed in the +Y longeron TPS closeout. The cracks also had 4 frost balls associated with them.

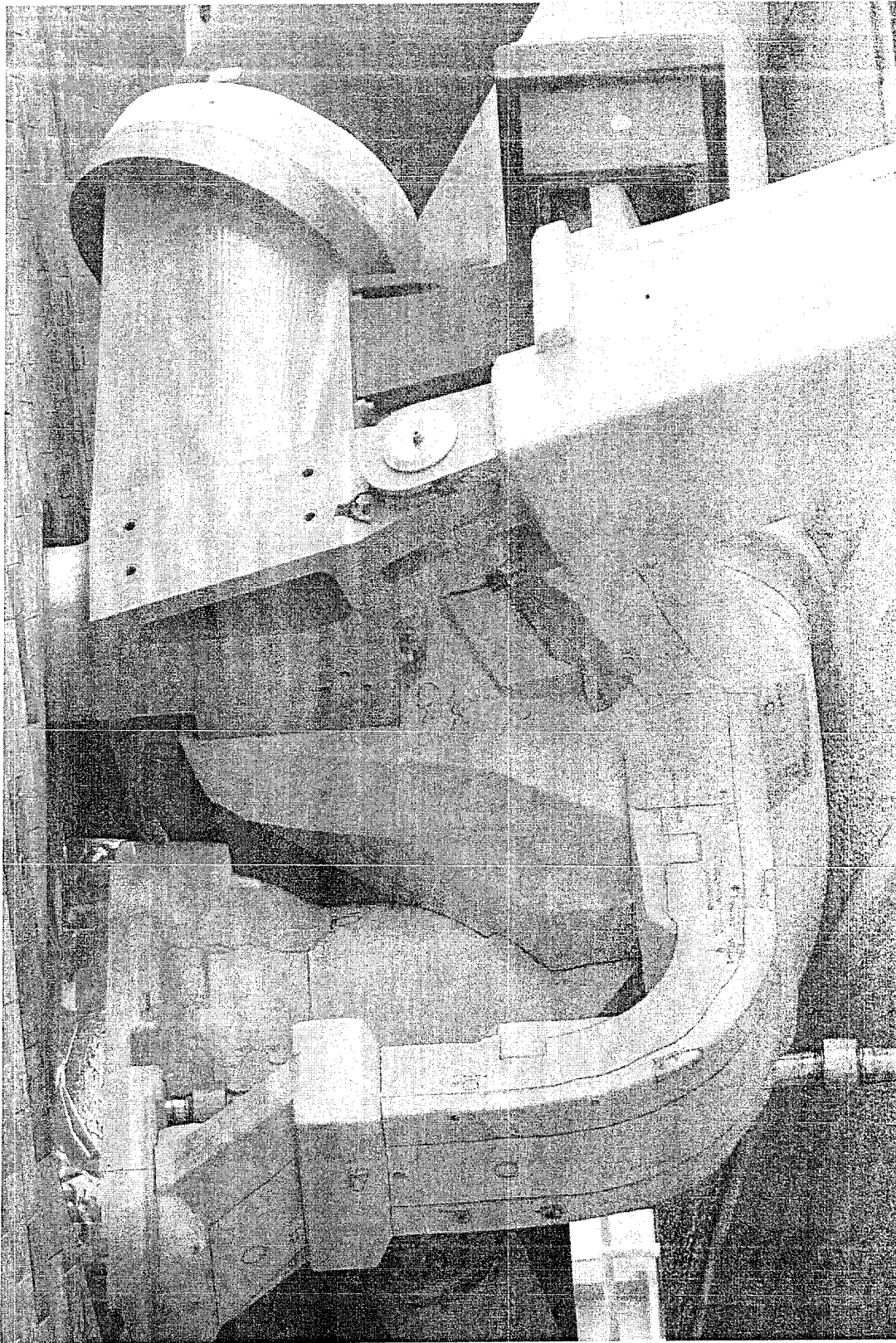


Photo 7: LO2 Umbilical area.
Ice/frost finger on pyro canister vent.

5.0 POST LAUNCH PAD DERBIS INSPECTION

The post launch inspection of the MLP-1, Pad A FSS, north flame trench, and Pad A apron was conducted on 05 June 2002 from Launch + 1.5 to 3.0 hours (1900 to 2030 EST).

No flight hardware was found.

Orbiter liftoff lateral acceleration data to predict stud hang-ups was received from Boeing-Huntington Beach and reported as inconclusive. Inspection was performed and the south holddown studs were visually assessed as having no indication of hang-up. Erosion was typical for both the north and south posts. North holddown post blast covers and T-0 umbilical exhibited nominal exhaust plume damage. Both SRB aft skirt GN2 purge lines were intact and erect, protective tape layering was partially eroded on both the RH and LH sides.

The LO2 and LH2 Tail Service Masts (TSM) appeared undamaged with both bonnets observed to have closed properly. The MLP deck was generally in good shape.

The GH2 vent line latched on the eighth of eight teeth on the latching mechanism. The vent line was located in a 'centered' position in the latching mechanism. The GUCP 7-inch quick disconnect probe was accessible for inspection and appeared to be undamaged with sealing surface in good shape. The deceleration cable was in nominal configuration, and the vent line blanket was sooted and torn. Film review should provide additional data for the assessment of vent line retract position.

The OAA appeared to be intact with no evidence of plume impingement. All slidewire baskets were secured with no evidence of damage.

The GOX vent arm, ducts and structure appeared to be in nominal condition. The GOX vent seals were inspected and found to be in good shape with only slight indication of ET paint residue present.

Debris findings included:

- FSS 115' level had an OTV camera pointed in the 'straight up' direction
- FSS 235' level 'Do Not Operate' tag that had been taped to preclude debris concern had the tape and tag heat shrunk and remained attached.

Overall damage to the pad appeared to be normal.

6.0 FILM REVIEW

No significant anomalies were observed during the review of the STS-111 Films/videos that required notification to the Mission Management Team, Shuttle managers, vehicle systems engineers, and to Program Integration.

6.1 LAUNCH FILM AND VIDEO SUMMARY

A total of 68 films and videos, which included 16mm films, 35mm films, and Operational Television Video (OTV) camera videos, were reviewed starting on launch day.

An apparent free-burning GH2 flash occurred at 21:22:45.541 GMT, approximately 1.5 seconds into SSME #1 start-up. This is later than what has been previously observed. (E-19, E-20, E-52, E-76, E-77)

GUCP separation and retraction appeared normal (E-33). GH2 vent line appeared to contact deceleration cable on center. Positive capture was achieved on the vent line latch with the latching mechanism centered in latching plate. (E-39) The hydrogen vent line pivot arm showed no rebound. (E-64)

Several ice particles from the GH2 disconnect fell at T-0. (E-33, E-34) Two ice particles contacted LH SRB shortly after T-0. No damage noted. (E-33)

Ice particles from LO2 feedline bellows or support bracket, blown westerly by wind, were observed near lower surface of LH wing. No contact with orbiter noted. (E-31, E-34)

Umbilical purge barrier baggie material fell during ascent. (E-52, E-54, E-207, E-222)

SRB separation appeared normal. (E-207, E-208, E-212)

Particles of SRB aft-skirt instafoam fell along side the SRB plume during ascent. (E-212, E-220, E-223)

OMS-assist firing was visible shortly after SRB separation. (E-207)

Localized flow condensation at various points on the vehicle appeared very pronounced during ascent. (E-207, E-208, E-212, E-213, E-222)

SSME Mach diamond formation sequence was 3-2-1. (E-76)

Body flap movement during ascent was typical. (E-207, E-212, E-220)

Ice particles fell from ET/ORB umbilicals after lift-off. No impact to orbiter lower surface was noted. (E-31, E-34, E-36, E-52, E-63)

Base heat shield movement during SSME ignition was typical. (E-76, E-77)

Charring on the ET aft dome was typical. (E-207, E-213, E-224)

Forward RCS paper covers were observed falling aft during early ascent. (E-52, E-54, E-207)

No stud hang up were observed on any of the SRB hold-down posts.

SRB holddown post shoe rocked slightly on HDP's #2 and #6. (E-8, E-13)
Small particle falls out from in between thermal curtain and SRB nozzle near HDP #6. (E-13)

Several small debris particles come loose from LO2 TSM access platform (north side) during SSME ignition. (E-17)

Deluge water pipe leaking near HDP 8. (E-14)

Free-burning GH2 blown under body flap by wind during SSME ignition.



Photo 8: SSME Flare approximately 1.5 seconds into startup sequence.

6.2 ON-ORBIT FILM AND VIDEO SUMMARY

16mm film motion picture films from the LH2 umbilical cameras, as well as the 35mm still images from the LO2 ET/ORB umbilical camera and Crew Hand-Held Still Images, of the External Tank after separation from the Orbiter were received and reviewed at KSC on 27 June 2002.

SRB separation from the External Tank appeared nominal.

ET separation from the Orbiter was normal.

No damage was detected on the LO2 ET/ORB umbilical disconnect, sealing surfaces, or closeout TPS. Typical ablation and divoting was noted on the vertical portion of the umbilical cable tray.

Three TPS divots, approximately 1.5 inches in diameter, were observed on the intertank-to-LH2 tank flange closeout near the +Y jack-pad closeout. No exposed substrate was noted. The jack-pad closeouts appeared in good condition.

One TPS divot, approximately 1.5 inches in diameter, was observed at the +Y bipod ramp-to-LH2 tank interface. This divot also appeared shallow with no substrate exposed.

One TPS divot was observed on an inter-tank stringer near the GO2 Press/Line ramp at station Xt -897. The divot is approximately 6 inches long by 2 inches wide and has exposed primed substrate. This is an area of the I/T that is not sanded and is not vented.

No anomalies were detected in the LO2 tank acreage. The BSM burn scars were typical. The Ogive had typical erosion.

The ablation/erosion of LO2 feedline flange.

6.3 LANDING FILM AND VIDEO SUMMARY

A total of 15 films and videos, which included eight 35mm large format films and nine videos, were reviewed.

The landing gear extended properly.

No anomalies were detected from touchdown through rollout.

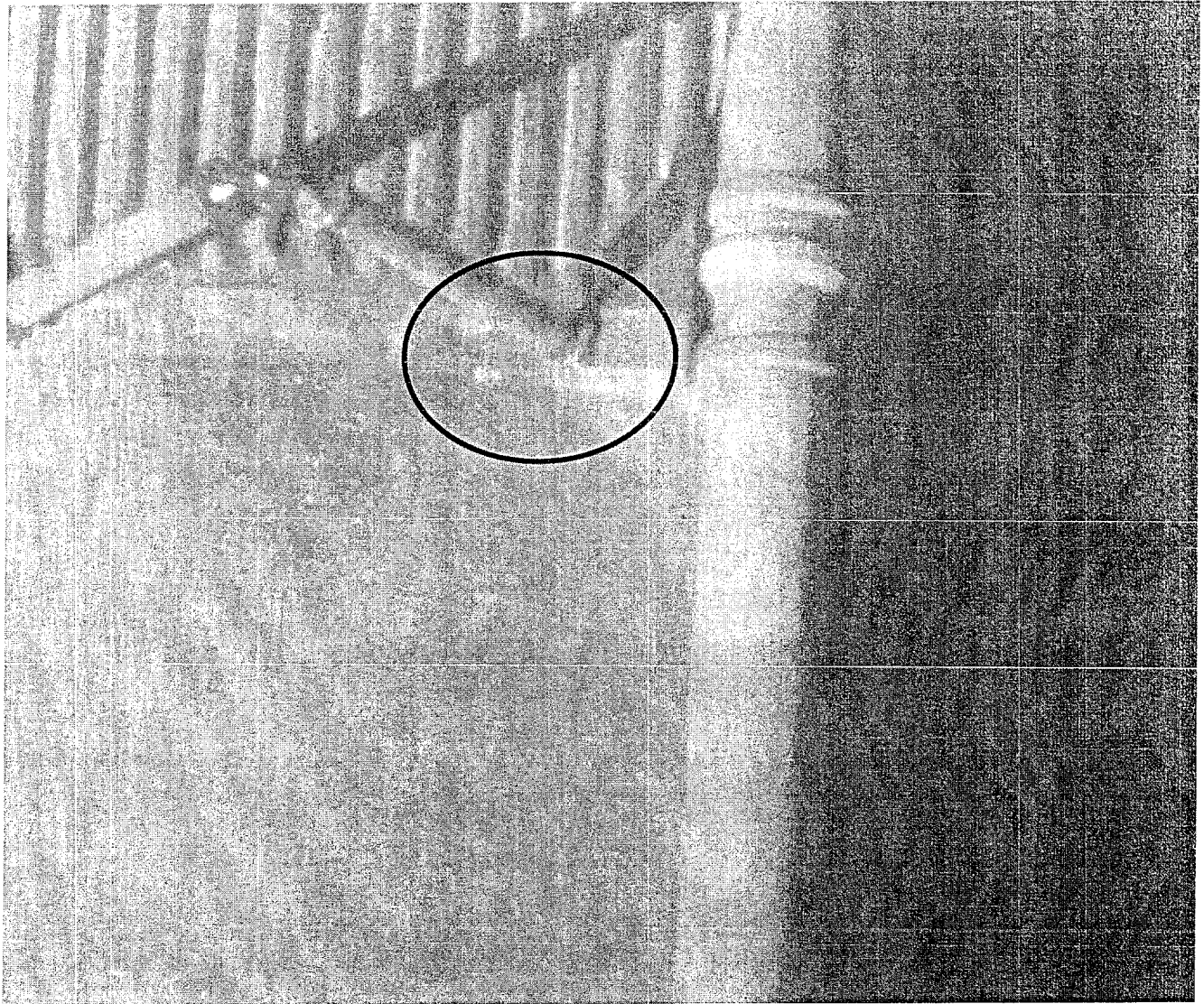


Photo 9: External Tank post-separation.

Three TPS divots, approximately 1.5 inches in diameter, were observed on the intertank-to-LH2 tank flange closeout near the +Y jack-pad closeout. One TPS divot, approximately 1.5 inches in diameter, was observed at the +Y bipod ramp-to-LH2 tank interface. The divots appeared shallow with no substrate exposed.

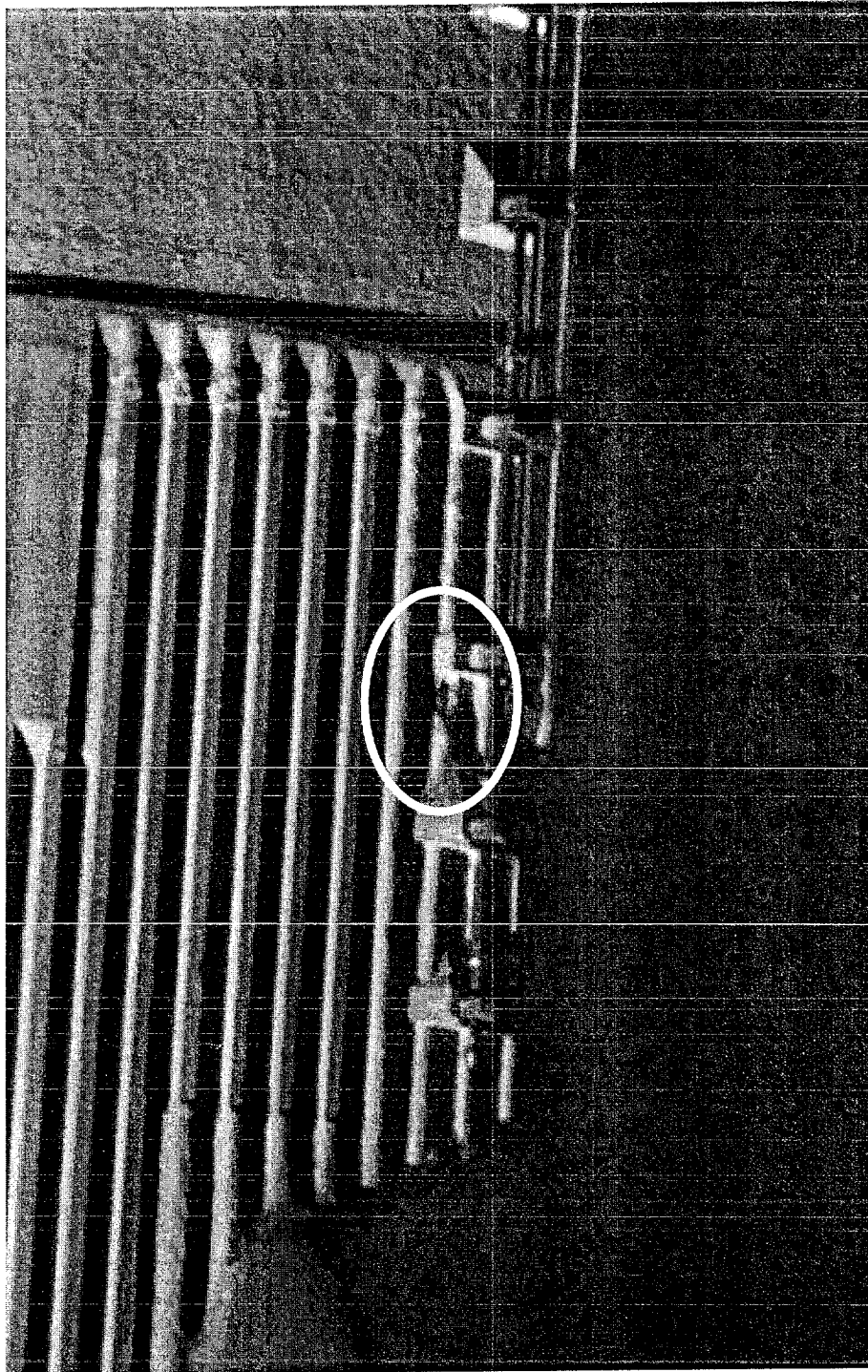


Photo 10: External Tank post-separation.

TPS divot (approximately 6 inches long by 2 inches wide) with exposed substrate located on an inter-tank stringer near the GO2 Press/Line ramp at station Xt -897.

7.0 SRB POST FLIGHT/RETRIEVAL DEBRIS ASSESSMENT

The BI-113 Solid Rocket Boosters were inspected for debris damage and debris sources at CCAFS Hangar AF on 10 June 2002. Overall, both boosters were in excellent condition.

The TPS on both frustums exhibited no debonds/unbonded. There was minor localized blistering of the Hypalon paint.

All eight BSM aero heat shield covers had fully opened and locked, but one RH and two LH cover attach rings had been bent at the hinge by parachute riser entanglement.

The forward skirts exhibited no debonds or missing TPS. RSS antennae covers/phenolic base plates were intact. All primary frustum severance ring pins and retainer clips were intact.

The Field Joint Protection System (FJPS) and the System Tunnel Covers closeouts were generally in good condition with no unbonds observed.

Separation of the aft ET/SRB struts appeared normal.

Aft skirt external surface TPS was in good condition. Typical blistering of Hypalon paint had occurred on the insulation close-outs and GEI cork runs.

The holddown post Debris Containment Systems (DCS) appeared to have functioned normally on all HDP's.

No indication of stud hang up was observed.

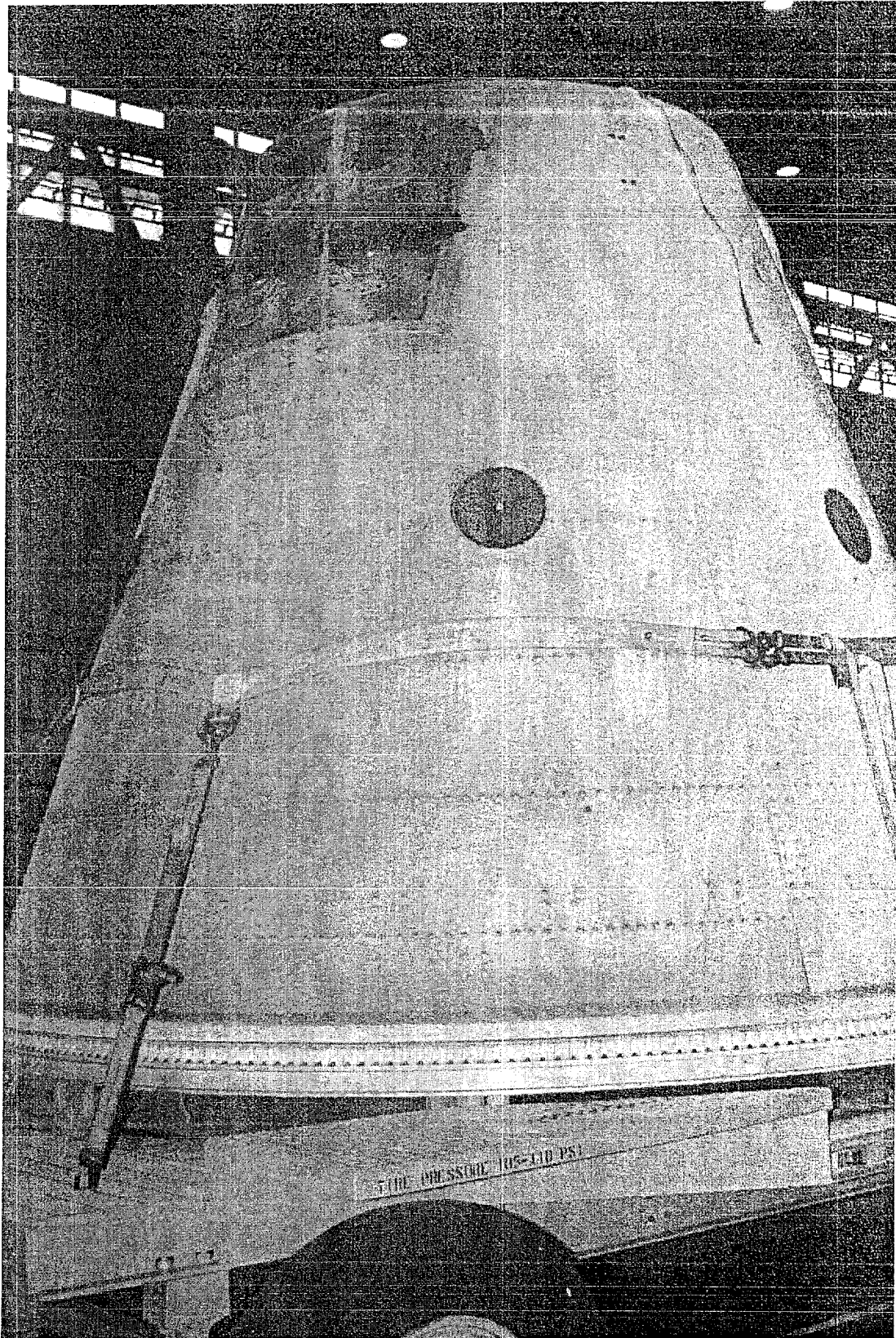


Photo 11: LH Frustum Post Flight Condition

The LH SRB frustum exhibited no debonds/unbonds or missing TPS.

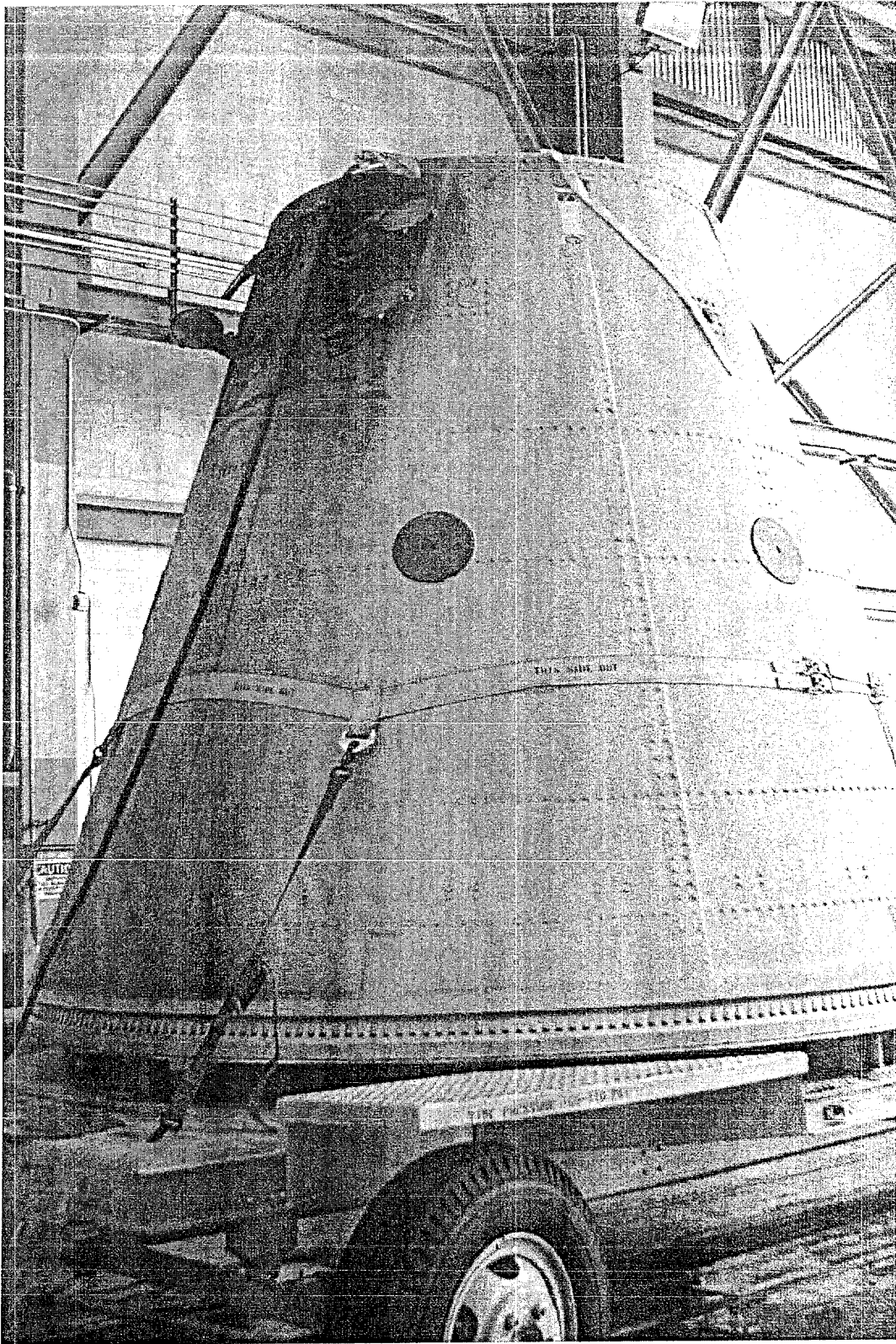


Photo 12: RH Frustum Post Flight Condition

The RH SRB frustum exhibited no debonds/unbonds or missing TPS. Note the cover attach ring bent at the hinge by parachute riser entanglement.

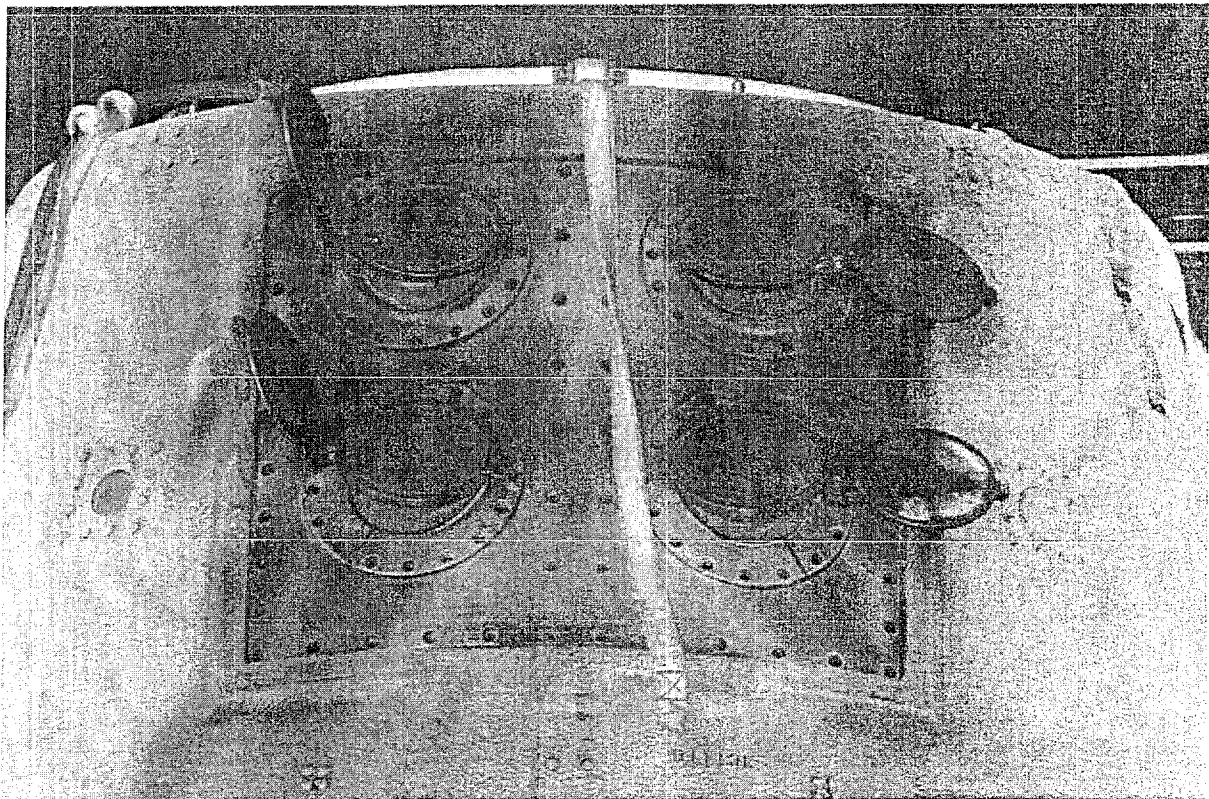


Photo 13: BSM Cover Condition

Two LH cover attach rings had been bent at the hinge by parachute riser entanglement.

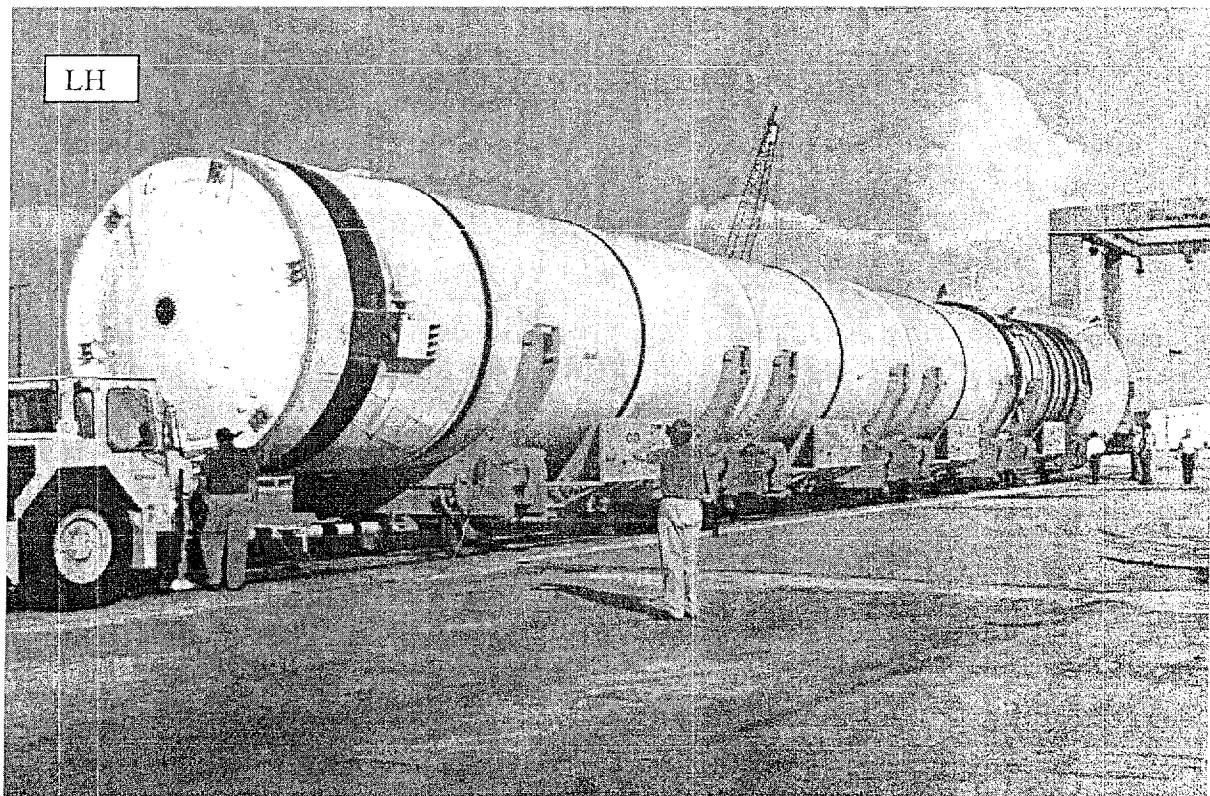


Photo 14: SRB Post Flight Condition

Both SRB's were found in good condition regarding debris assessment

8.0 ORBITER POST LANDING DEBRIS ASSESSMENT

After the 10:58 a.m. local/pacific time landing on 19 June 2002, a post landing inspection of OV-105 Endeavour was conducted at the Edwards Air Force Base on Runway 22 and at the Mate-Demate Facility (MDD). This inspection was performed to identify debris impact damage and, if possible, debris sources.

The Orbiter TPS sustained a total of 79 hits of which 26 had a major dimension of one-inch or larger. This total does not include the numerous hits on the base heat shield attributed to SSME vibration/acoustics and exhaust plume re-circulation.

The following table lists the STS-111 Orbiter damage hits by area:

| | HITS \geq 1-inch | TOTAL HITS |
|---------------|--------------------|------------|
| Lower Surface | 21 | 47 |
| Upper Surface | 1 | 6 |
| Window Area | 3 | 19 |
| Right Side | 0 | 4 |
| Left Side | 1 | 3 |
| Right OMS Pod | 0 | 0 |
| Left OMS Pod | 0 | 0 |
| TOTALS | 26 | 79 |

The Orbiter lower surface sustained 47 total hits, of which 21 had a major dimension of one inch or larger. Both of these numbers are within family. A total of 19 hits occurred on the lower surface between the nose landing gear and the main landing gears, with 8 of these hits having a major dimension of one inch or greater. Nine of the 19 damage sites between the landing gears occurred on the right-hand wing glove.

The largest hit on the lower surface measured 3" x 1/2" x 3/8" and was located to the left of the centerline between the main landing gear wheel wells. The second largest hit on the lower surface measured 3" x 1/4" x 3/8" and was located aft of the nose landing gear door, at approximately the same position to the left of the centerline. Both of these hits had relatively large length to width ratios. The similarity of a) the outboard locations of these two hits, and b) the large length to width ratio suggests they may be from the same source.

A total of 14 of the lower surface hits were located in the vicinity of the LH2 umbilical door. Most of these damage sites were caused by pieces of the umbilical purge barrier flailing in the airstream and impacting the TPS tiles before detaching.

A triangular-shaped tile corner (measuring approximately 2 1/2" by 2 1/2") was missing. The location of the missing tile piece was the inboard end of the right hand inboard elevon, approximately one third of the elevon chord length downstream of the leading edge.

Damage sites on the window perimeter tiles were less than usual in quantity. There were a total of 19 hits on the window perimeter tiles with 3 having dimensions greater than one inch. Damage to the window perimeter tiles on the forward facing windows is attributed to impact by forward RCS paper covers with RTV adhesive on the back.

Moderate hazing was noted on the upper portion of windows 2, 3, 4 and 5. In addition to hazing, streaks were observed on windows 3 and 4. The streaks may be the result of impacts by RTV adhesive used on the forward RCS paper covers.

The main landing gear tires were reported to be in typical condition for landing on a concrete runway. The main landing gear inboard tires both had damage on the second tread from the inboard side.

ET/Orbiter separation devices EO-1, EO-2, and EO-3 were reported to have functioned normally. No ordnance fragments were found on the runway beneath the umbilicals. Several of the EO-2 fitting retainer clips were missing. The EO-2 and EO-3 pyro shutters were fully closed.

There was less than usual tile damage on the Orbiter base heat shield. The SSME Dome Heat Shield closeout blankets were in good overall condition. Slight fraying was observed on the SSME #1 blanket at the 6 o'clock position. Two large damage sites (approximately 3-inches by 3-inches) on the body flap upper surface tiles adjacent to the body flap stub, appear to be failed repairs.

A post landing walk-down of the runway was performed by the rollout measurement team and no flight hardware was found. All components of the drag chute were recovered and appeared to have functioned normally. Both reefing and line cutter pyrotechnic devices were expended.

In summary, both the total number of Orbiter TPS debris hits and the number of hits one-inch or larger were well within established family.

Orbiter Lower Surface Debris Damage Locations

Lower Surface Hits

Hits = 47

Hits > 1 inch = 21

All dimensions in inches

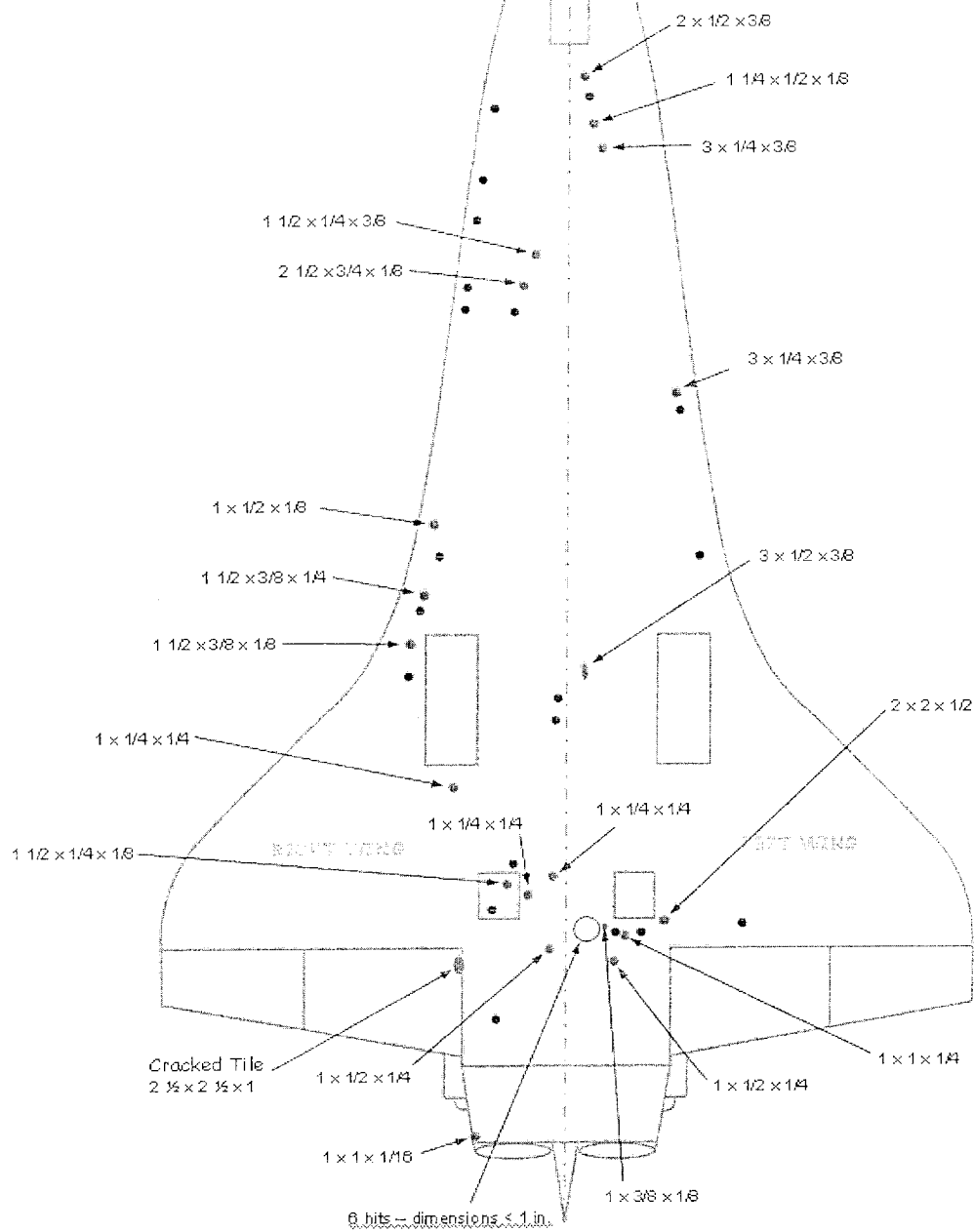


Figure 1: Orbiter Lower Surface Debris Damage Map

STS-101 DEBRIS DAMAGE LOCATIONS

Upper Surface Hits

Hits = 26

Hits > 1 inch = 4

All dimensions in inches

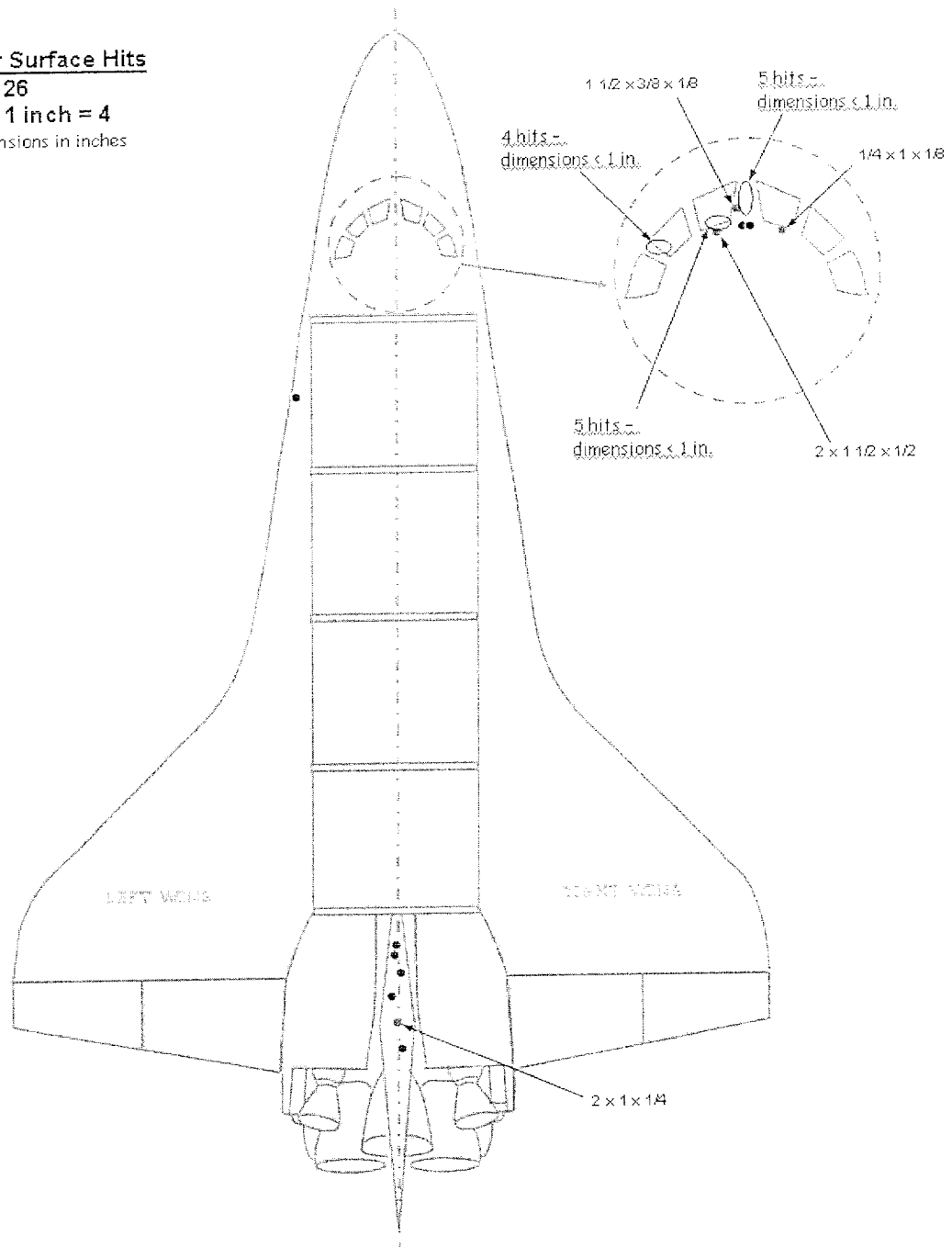


Figure 2: Orbiter Upper Surface Debris Damage Map

STG-111 DEER'S DAMAGE LOCATIONS

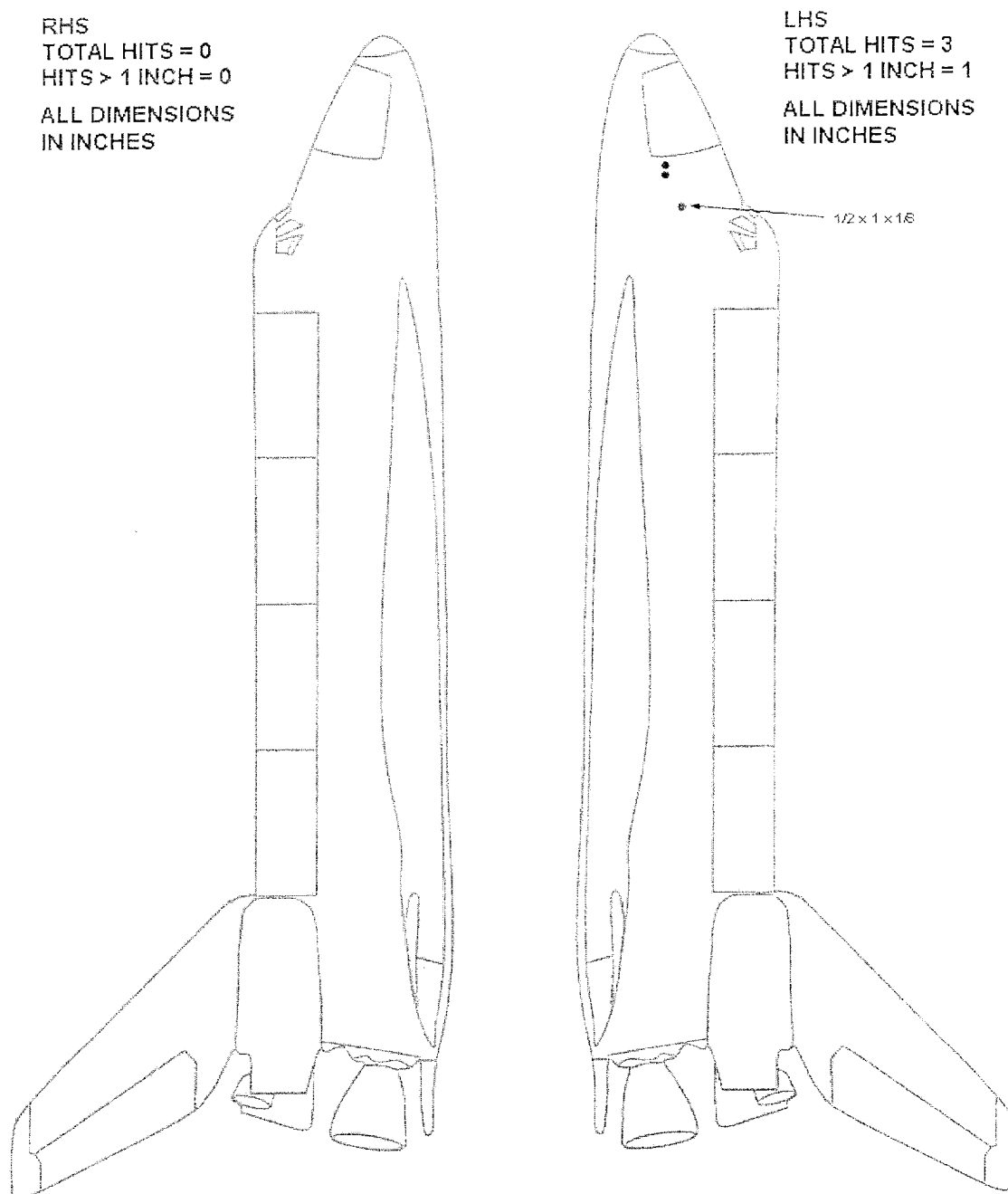


Figure 3: Overall View of Orbiter Sides

| STS NUMBER | LOWER SURFACE | | ENTIRE SURFACE | |
|------------|---------------|------------|----------------|------------|
| | HITS > 1 INCH | TOTAL HITS | HITS > 1 INCH | TOTAL HITS |
| STS-70 | 5 | 81 | 9 | 127 |
| STS-89 | 22 | 175 | 27 | 198 |
| STS-73 | 17 | 102 | 26 | 147 |
| STS-74 | 17 | 78 | 21 | 116 |
| STS-72 | 3 | 23 | 8 | 55 |
| STS-75 | 11 | 55 | 17 | 96 |
| STS-76 | 5 | 32 | 15 | 69 |
| STS-77 | 15 | 48 | 17 | 81 |
| STS-78 | 5 | 35 | 12 | 85 |
| STS-79 | 8 | 65 | 11 | 103 |
| STS-80 | 4 | 34 | 8 | 93 |
| STS-81 | 14 | 48 | 15 | 100 |
| STS-82 | 14 | 53 | 18 | 103 |
| STS-83 | 7 | 38 | 13 | 81 |
| STS-84 | 10 | 67 | 13 | 103 |
| STS-94 | 11 | 34 | 12 | 90 |
| STS-85 | 6 | 37 | 13 | 102 |
| STS-99 | 21 | 75 | 25 | 88 |
| STS-101 | 19 | 70 | 27 | 113 |
| STS-106 | 17 | 73 | 17 | 105 |
| STS-92 | 14 | 86 | 24 | 127 |
| STS-97 | 10 | 78 | 10 | 84 |
| STS-98 | 8 | 73 | 13 | 102 |
| STS-102 | 10 | 44 | 15 | 100 |
| STS-100 | 4 | 42 | 13 | 92 |
| STS-104 | 24 | 108 | 26 | 126 |
| STS-105 | 15 | 108 | 25 | 144 |
| STS-108 | 17 | 81 | 22 | 95 |
| STS-109 | 14 | 63 | 18 | 98 |
| STS-110 | 18 | 70 | 22 | 110 |
| AVERAGE | 12.2 | 65.9 | 17.0 | 104.4 |
| SIGMA | 5.9 | 30.9 | 6.2 | 26.6 |
| STS-111 | 21 | 47 | 26 | 79 |
| | | | | |

MISSIONS STS-86,87,89,90,91,95,88,96,93,103 ARE NOT INCLUDED SINCE THESE MISSIONS HAD SIGNIFICANT DAMAGE CAUSED BY KNOWN DEBRIS SOURCES

Figure 4: Orbiter Post Flight Debris Damage Summary

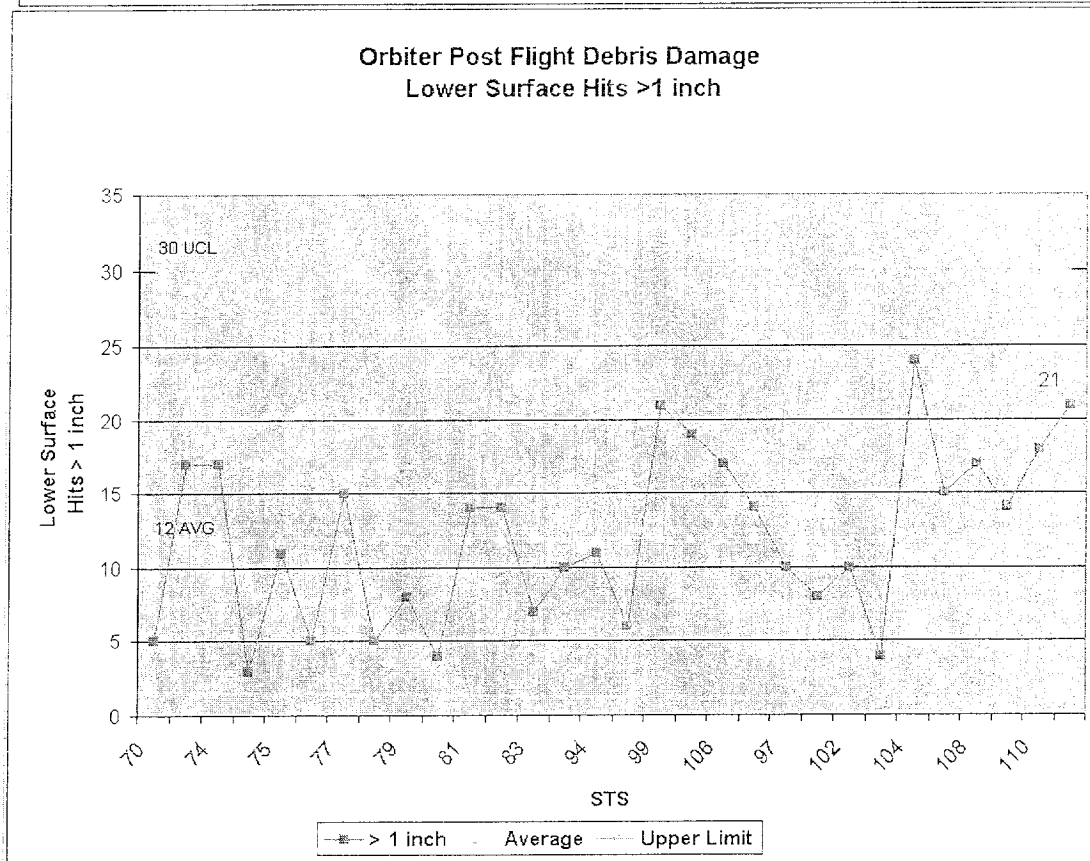
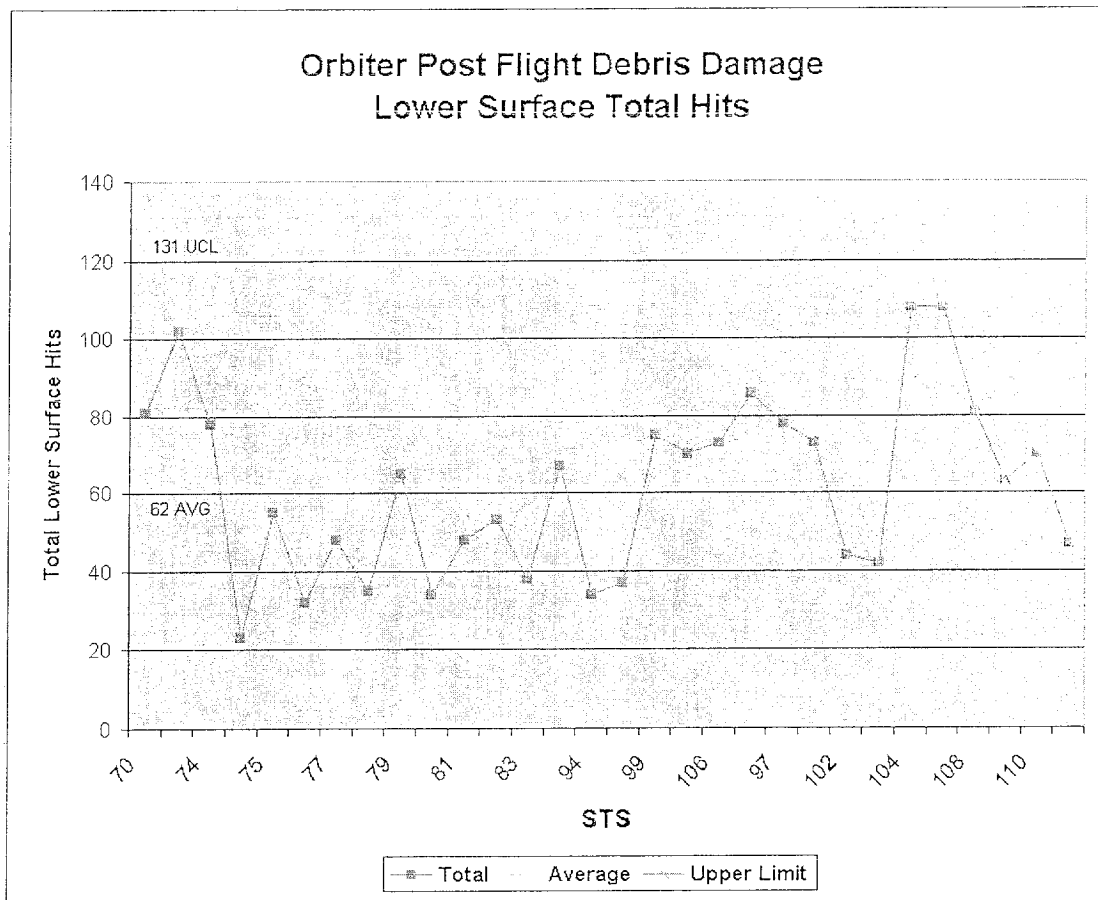


Figure 5: Control Limits for Lower Surface Hits

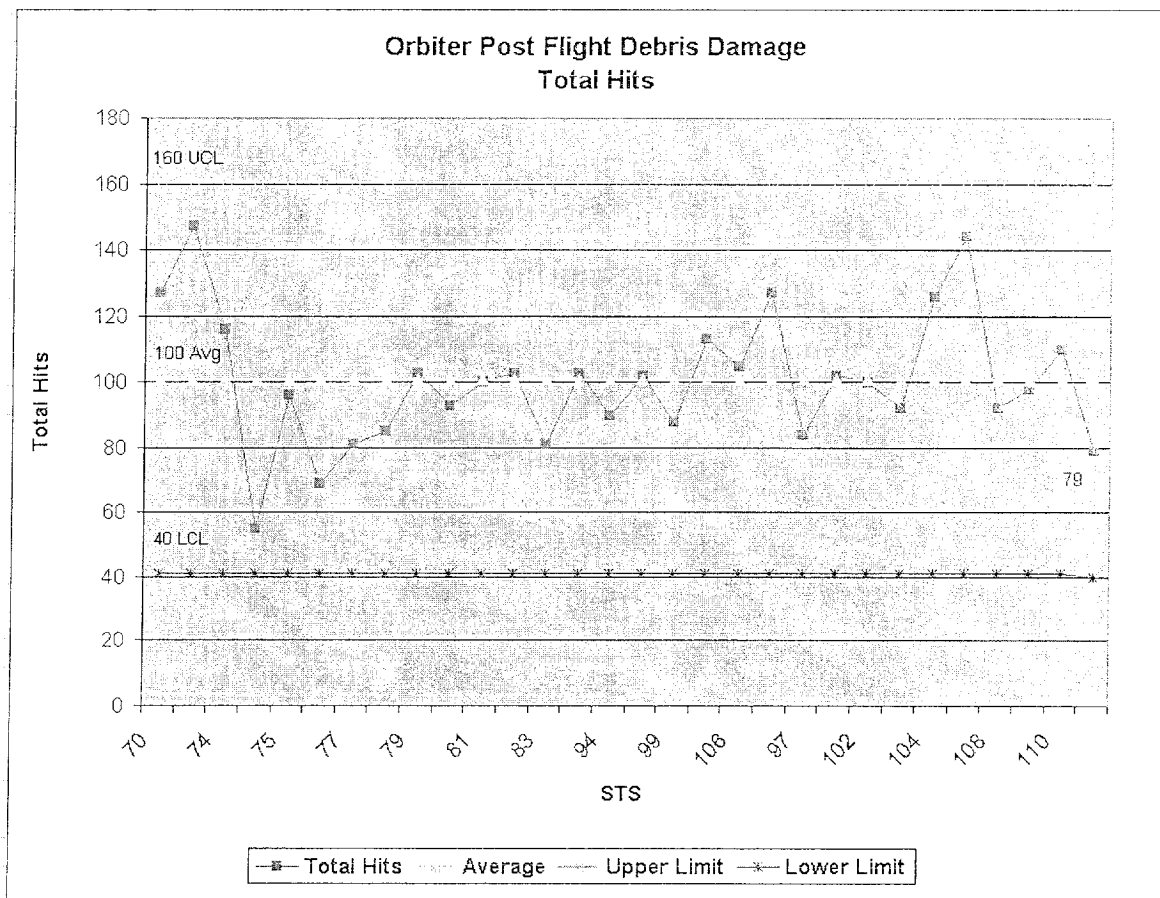
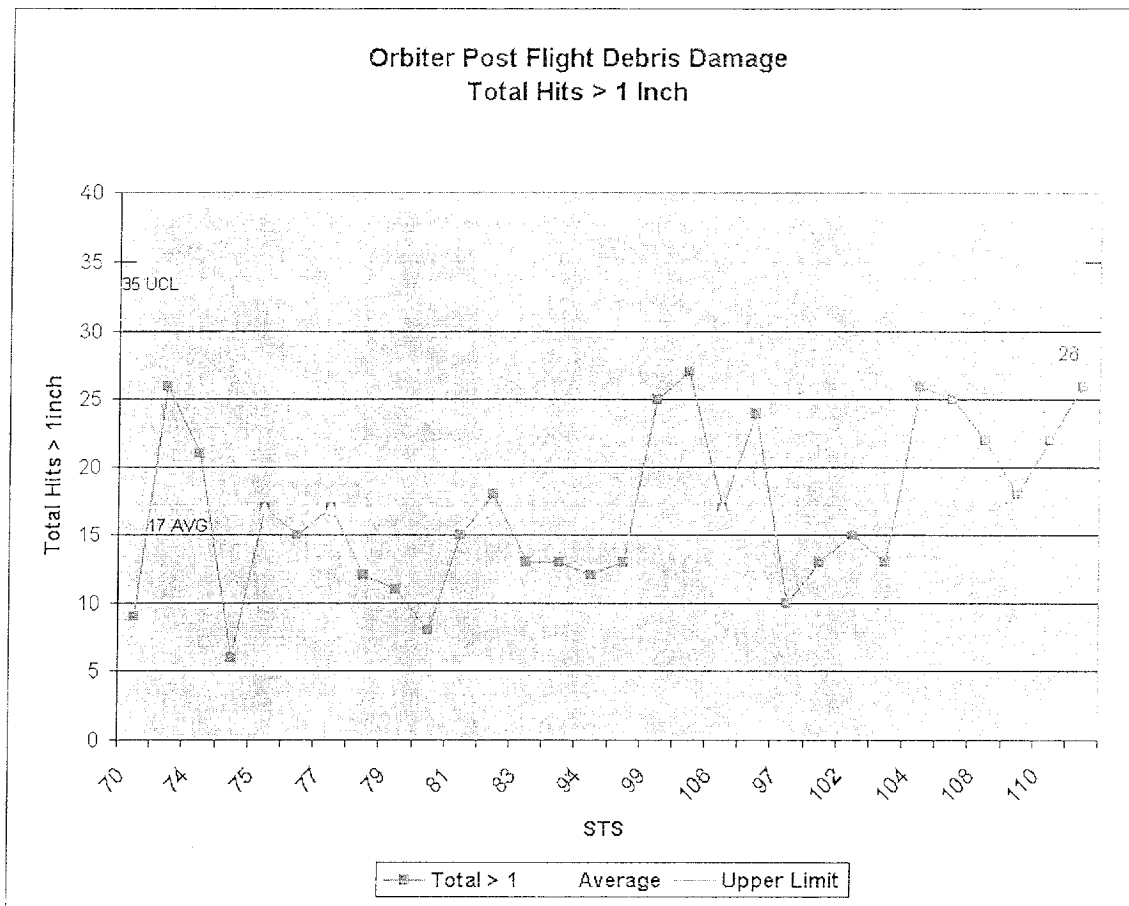


Figure 6: Control Limits for Total Hits

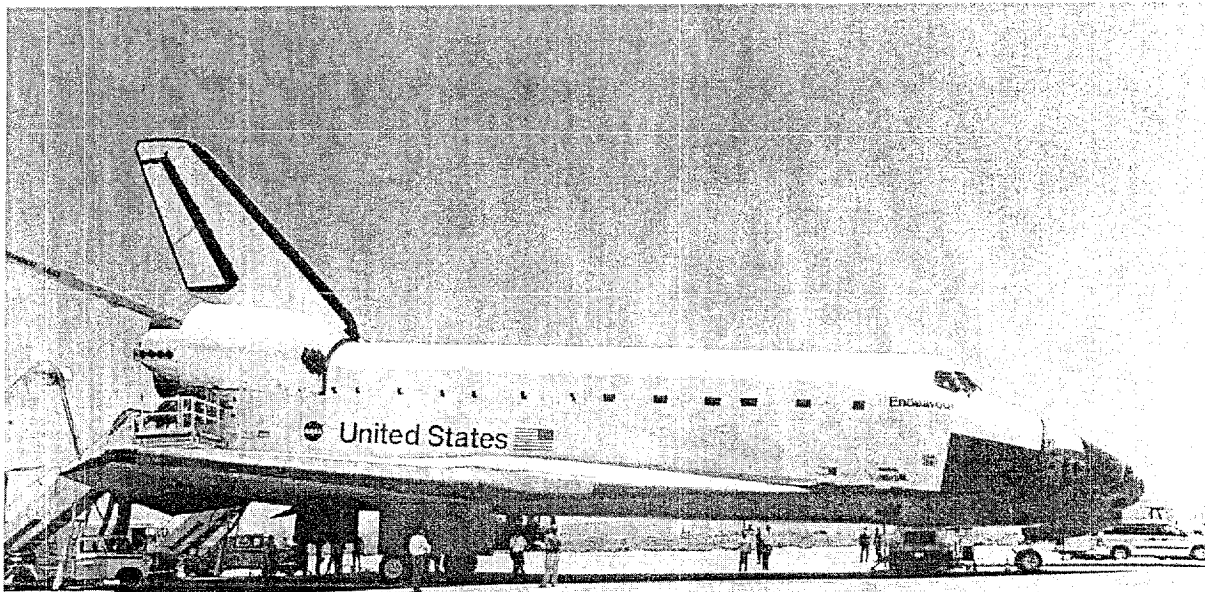
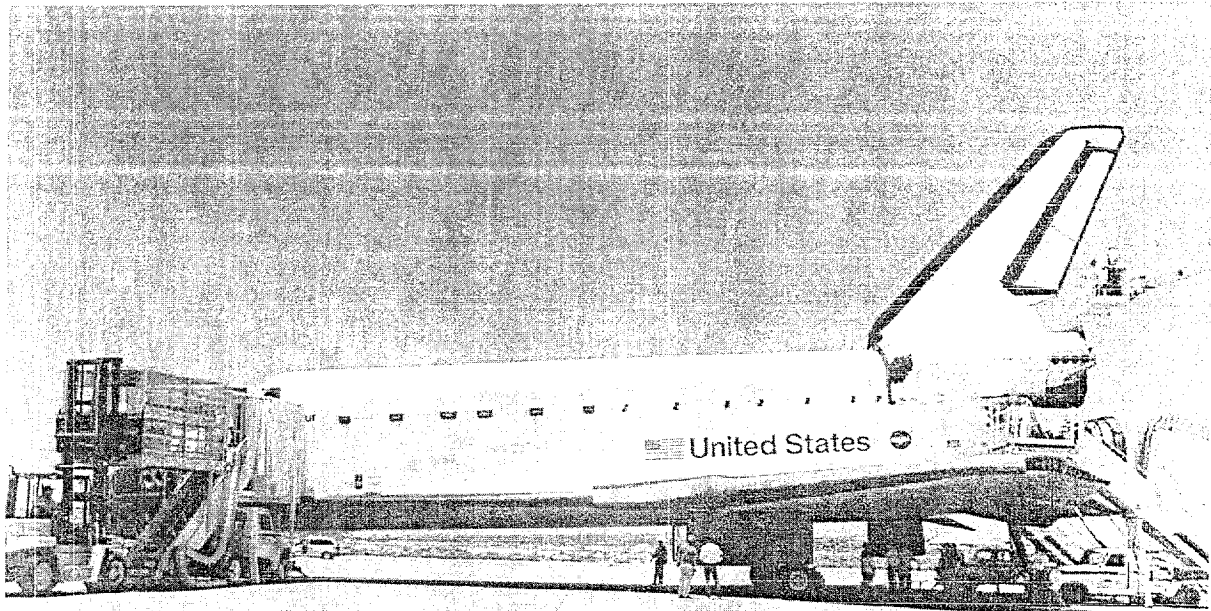


Photo 15: Overall View of Orbiter sides

The Orbiter lower surface sustained 47 total hits, of which 21 had a major dimension of one inch or larger. Both of these numbers are within family.

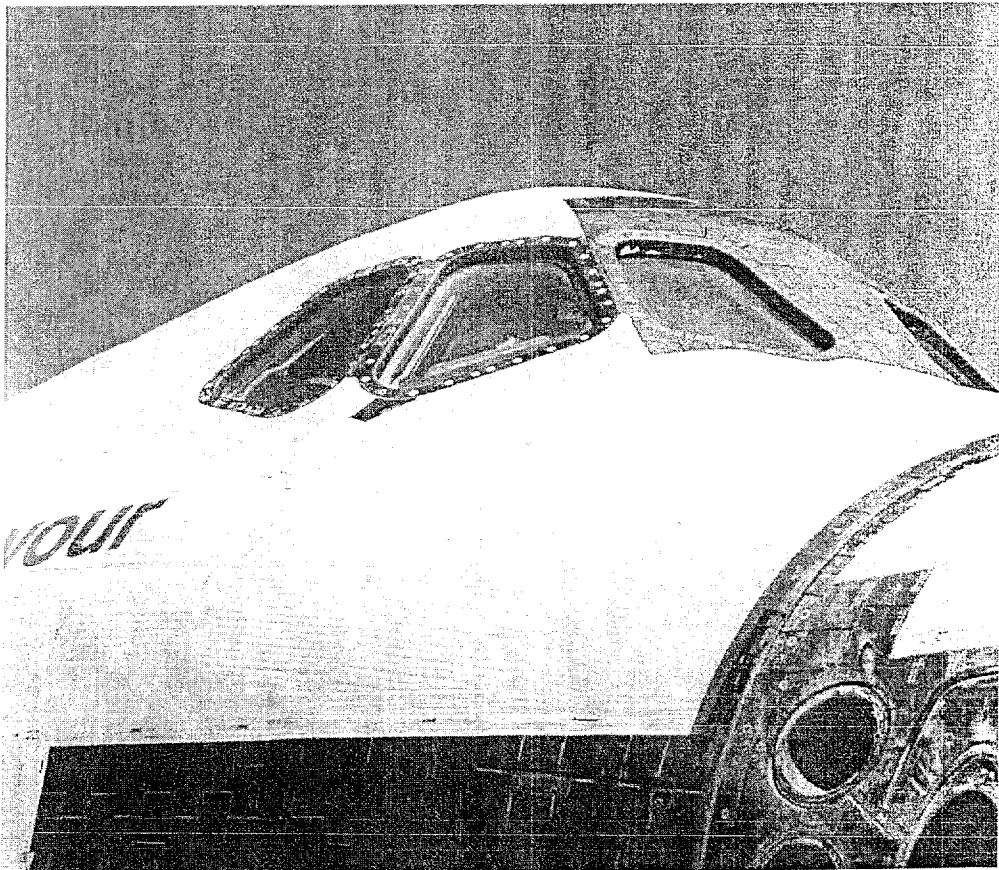
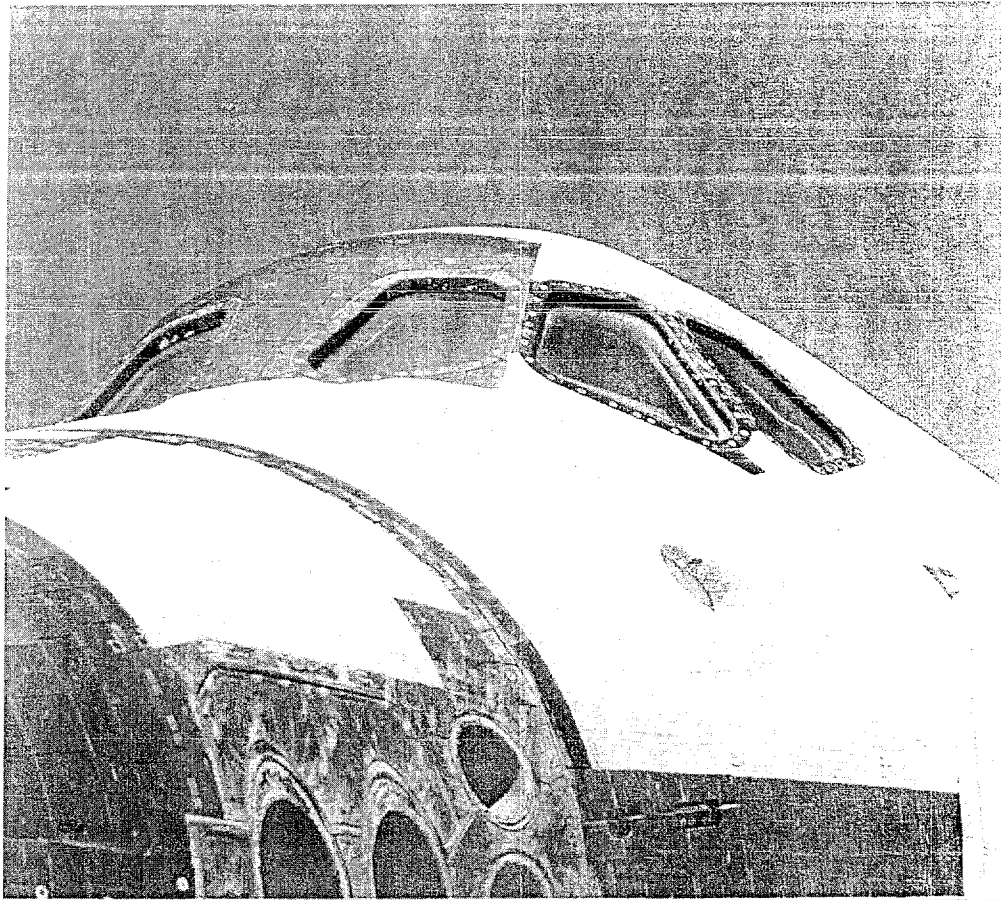


Photo 16: Overall View of Orbiter Windows

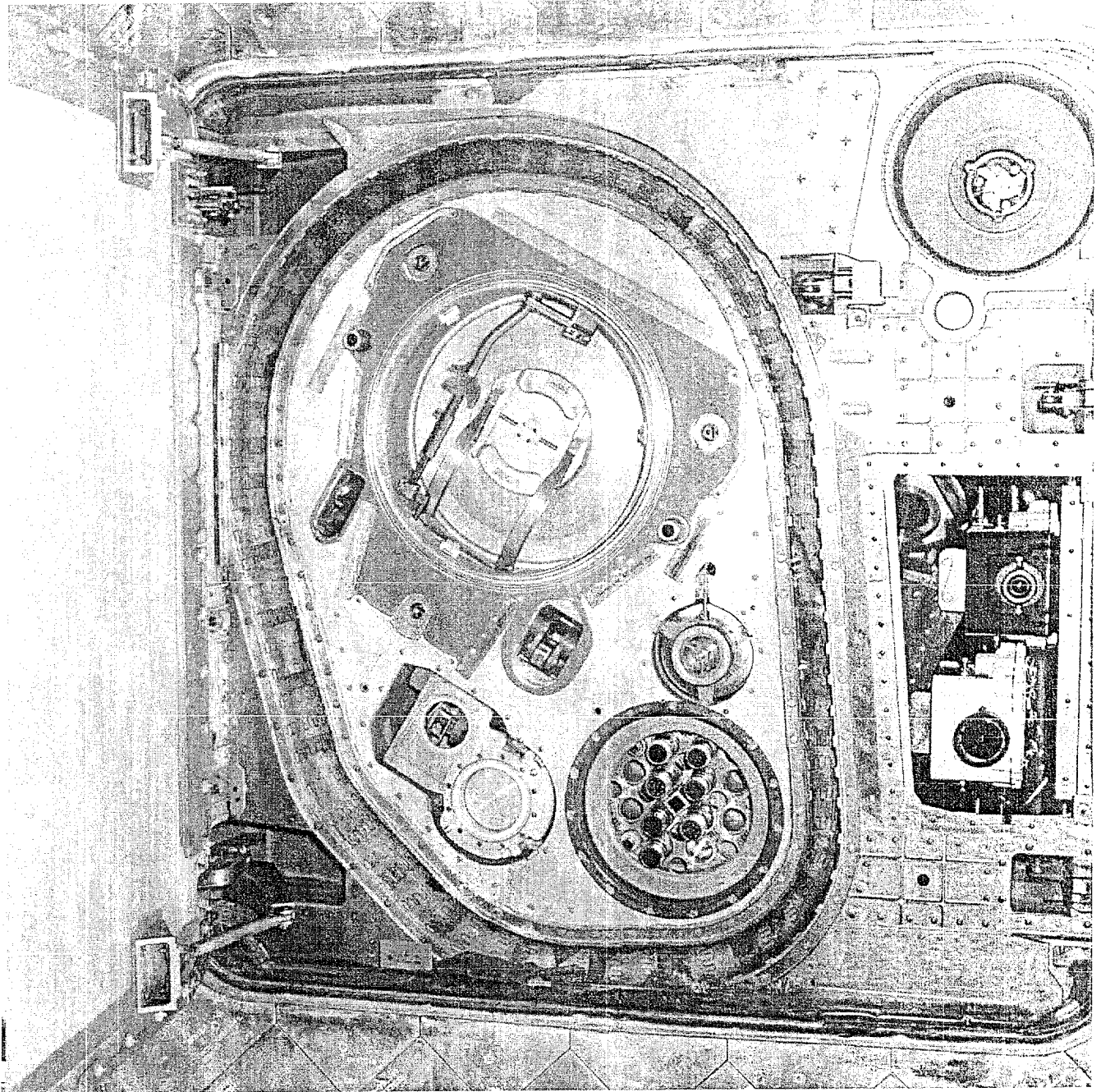


Photo 17: ORB/ET LH2 Umbilical

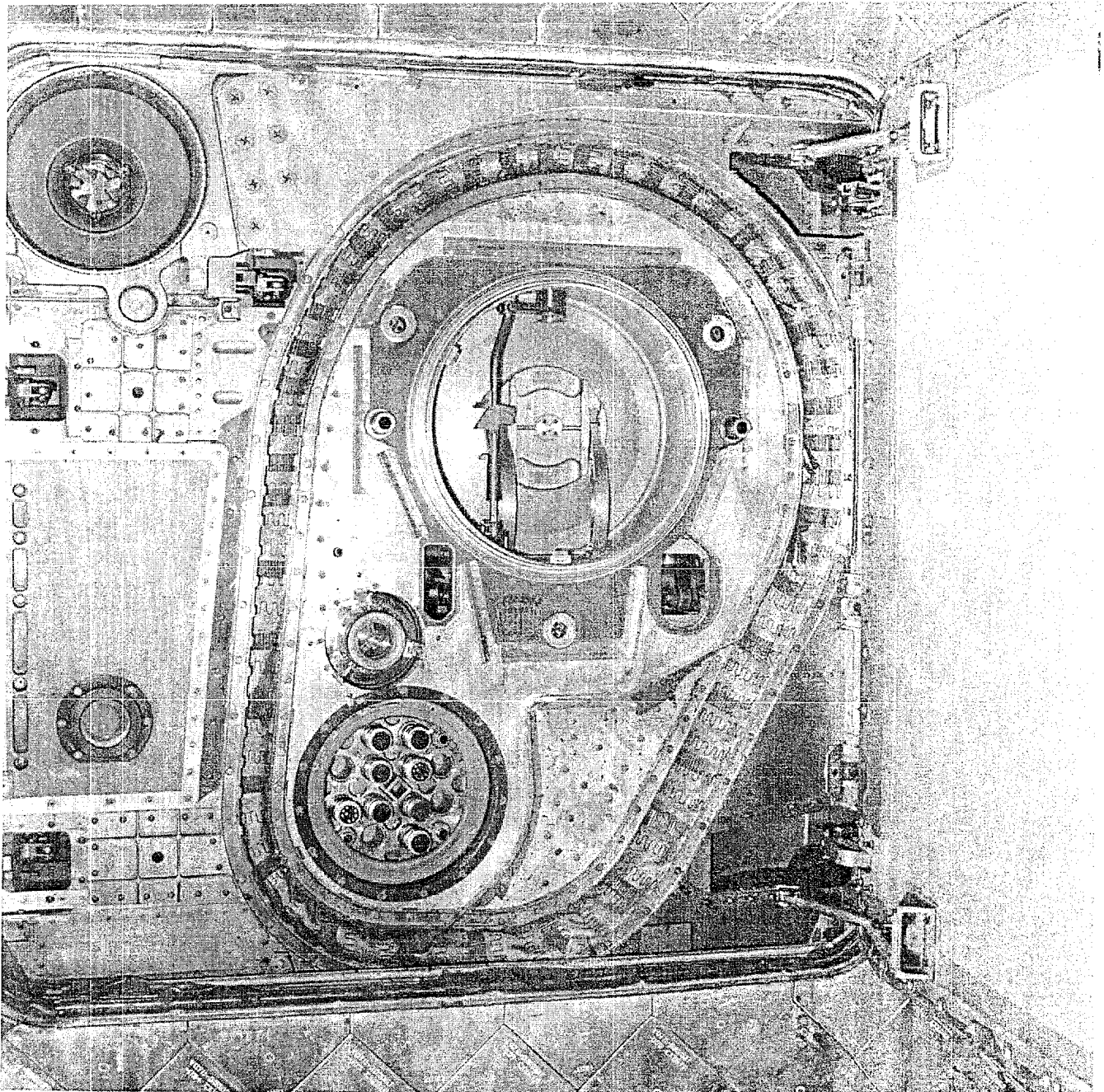


Photo 18: ORB/ET LO2 Umbilical

9.0 DEBRIS SAMPLE LAB REPORTS

Window wipe samples from Orbiter windows 1 thru 8 were submitted to the KSC Microchemical Analysis Branch (MAB) for material/chemical identification analysis and comparison to known STS materials. The results of this analysis are summarized below.

Sample residuals provided indication of Orbiter Thermal Protection System (TPS) materials, metallics and metallic corrosion, paint, natural landing site, and organic materials.

The organic material analysis provided indication of proteinaceous (as in insect remains), polyurethane (window cover), and silicone (RCS thruster cover/Orbiter TPS) materials.

Post-landing sample results provided no new information or trend data for debris source analysis.

10.0 POST-LAUNCH ANOMALIES

Based on the debris walkdowns and film/video review, the only post-launch anomaly candidate was the unusual flare in the SSME exhaust during the startup sequence.

APPENDIX A. JSC PHOTOGRAPHIC ANALYSIS SUMMARY

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Summary of Significant Events

1 STS-111 (OV-105): Film/Video Screening and Timing Summary

1.1 Screening Activities

1.1.1 Launch

The STS-111 launch of Endeavour (OV-105) from Pad A occurred on June 5, 2002 at 156:21:22:49.017 UTC as seen on the LSRB holddown post M-5 camera E12. SRB separation occurred at approximately 156:21:24:52.907 UTC as seen on camera E223.

On launch day, 24 videos were received and screened. Timing data was received on the long range tracking views (second engineering replays) except for camera ET207 which did not have the IRIG timing. Analysis of the long range tracking views was hindered by clouds and haze.

Twenty-six launch films were screened and a report was sent to the Shuttle Program distribution on June 8, 2002. This includes films E39 and E61 that were provided in support of the STS-108 hydrogen vent umbilical anomaly (SR-1652). Twenty-one additional films were received for contingency support and anomaly resolution.

Three anomaly candidates were seen during the review of the STS-111 launch films and videos that were elevated to the Launch + 4 Day KSC, JSC, MSFC Film/Video Analysis Teams Consolidated Film Review Reports. (This report consolidates the multi-center post flight photo reviews into a single list of observations for engineering review. This integrates the photo review process into the IFA / PRACA process to ensure that the identified observations are assessed and dispositioned prior to the next flight per established problem reporting criteria). No anomalous events were seen on the on-board films that view the (left) Solid Rocket Booster and the External Tank.

Two 16mm umbilical well cameras and the 35mm umbilical well TPS camera flew on STS-111 (the new 35mm umbilical well camera was not used on STS-111). See section 2.3. Crew handheld still photography and video of the External Tank was also acquired on STS-111.

1.1.2 On-Orbit

No unplanned on-orbit Shuttle support tasks were requested. Pre-planned, real-time analysis support was provided to the ISS UF-2 Space Station photographic and television external survey. The Space Station image analysis support will be documented in the UF-2 Imagery Overview Report.

Summary of Significant Events

1.1.3 Landing

Endeavour made a day landing on runway 22 at Edwards Air Force Base on June 19, 2002 (170:17:57:41.288 UTC). Eleven videos and ten landing films were received.

The approach to landing, touch down, drag chute deploy, and landing roll-out appeared normal on the landing imagery. No damage to the drag chute was detected. The drag chute appeared to deploy straight aft on the landing imagery views.

Post landing, a sink rate analysis of the STS-111 main landing gear was performed for the main gear touchdown. See Section 2.5.

2 Summary of Significant Events

2.1 KSC, JSC, MSFC Film/Video Analysis Teams Launch + 4 Day Intercenter Consolidated Film Review Report

Three anomaly candidates were noted during the review of the STS-111 launch films and videos that were elevated to the Launch + 4 Day KSC, JSC, MSFC Film/Video Analysis Team Consolidated Film Review Report. No anomalies were reported on the Landing + 3 Day Intercenter Consolidated Film Review Report.

CFVR-111-01: Orange Colored Flash



Figure 2.1 (A) Orange Flash Seen in SSME #1 During Ignition (Camera E2)

Summary of Significant Events

A large, late-occurring, orange-colored flash (probably free burning hydrogen) was seen in the +Z /-Y direction from the SSME #1 rim during SSME ignition (21:22:45.541 UTC). On the close-up camera E20 view, the flash appeared to originate within or just below the rim of SSME #1 (21:22:45.537 UTC). A second smaller flash was visible aft of the larger flash (Cameras E2, E19, E20, E52, E63, E76). The previous mission STS-110 launch video was reviewed and a similar but much smaller flash near SSME #1 was also present during the STS-110 SSME ignition. (The STS-110 flash occurred 1.5 seconds prior to the SSME #1 Mach diamond formation compared to STS-111 where the flash occurred 1.2 seconds prior to the SSME #1 Mach diamond formation.). No out-of-family flashes were seen on the STS-108 and STS-109 videos.

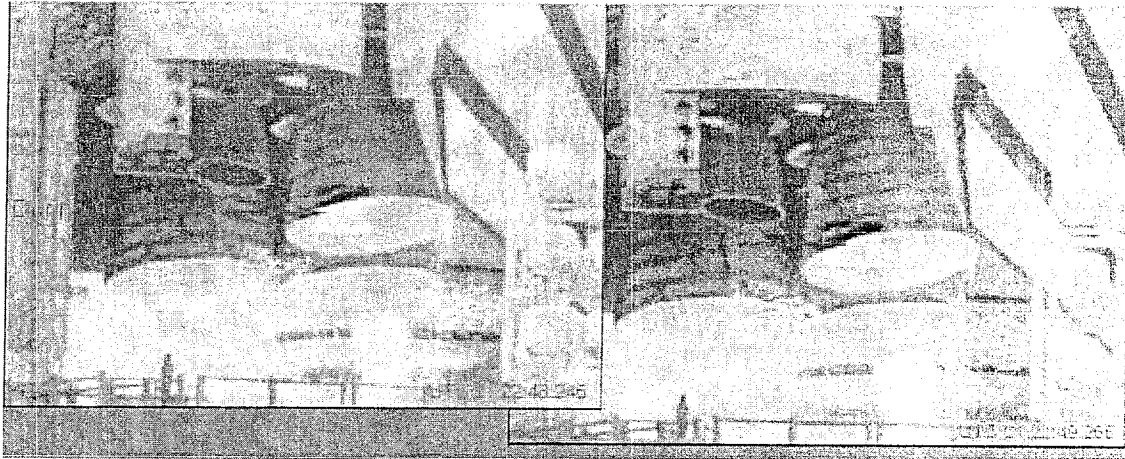


Figure 2.1 (B) Light Colored Area on Inside of SSME #1 (Camera E77)

A light colored area was seen on the inside of SSME #1 that may have been an indication of a hot wall leak. However, KSC reported that the view was showing a small area of turbulence inside the SSME #1 engine that was caused by weld beads.

Summary of Significant Events

CFVR-111-02: RSRB Holddown Post M-3 Blast Deflection Shield Closed Late

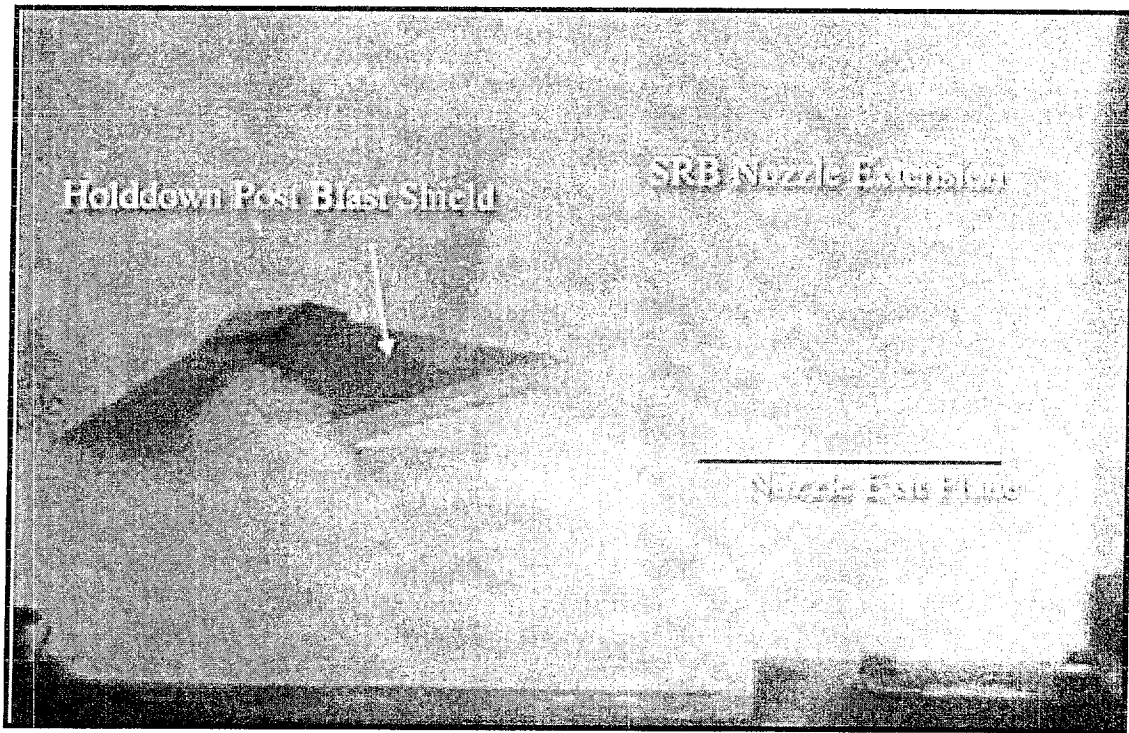


Figure 2.1 (C) Holddown Post Blast Shield Closes Late (Camera E10). Image Courtesy of Marshall Space Flight Center.

The blast deflection shield on the RSRB holddown post M-3 did not close until after the SRB nozzle exit plane had cleared the holddown post during liftoff (21:22:50.015 UTC). (Cameras E10, E15)

Summary of Significant Events

CFVR-111-03: Ablative Material Protruding from -Z Rim of SSME #2 and from the +Y Rim of SSME #3

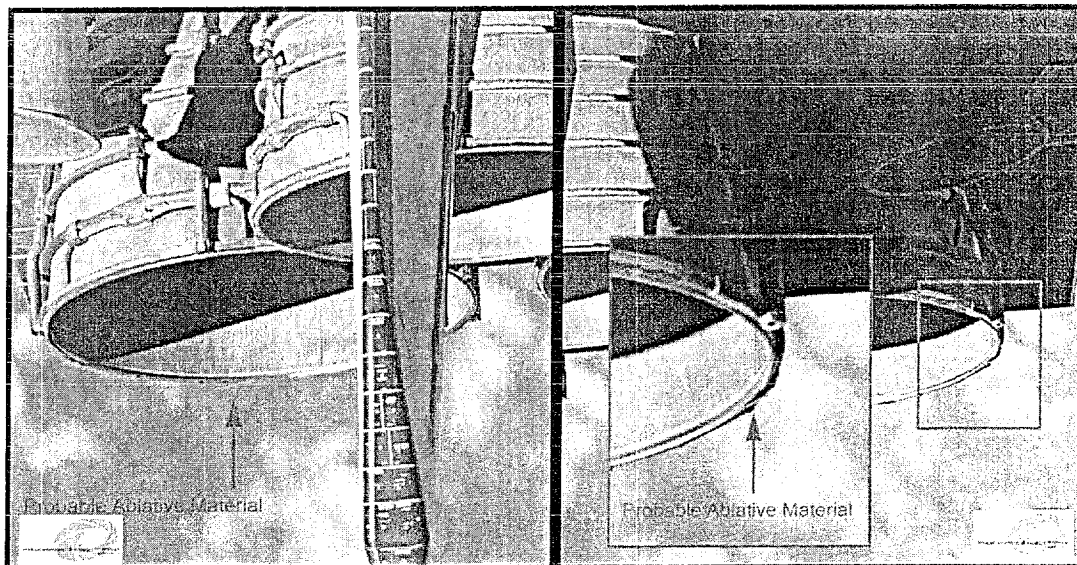


Figure 2.1 (D) Ablative Material on SSME Rims Seen On-Orbit (ISS004E13276)

Thin, red colored objects (ablative material) were seen protruding from the edge of the -Z rim of SSME #2 and from the +Y edge of SSME #3 on the downlinked digital imagery prior to landing.

2.2 Other Launch Observations

2.2.1 Debris from SSME Ignition through Liftoff

A piece of ice debris was seen to contact the rim of SSME #3 prior to liftoff (21:22:46.082 UTC). No damage to the engine rim was noted. (Camera E76)

A single piece of light-colored debris was seen falling along the Orbiter fuselage tiles during liftoff (21:22:48.987 UTC). The debris may have contacted the fuselage tiles, however no damage to the tiles was detected. The source of the debris may have been frost/ice from the forward ET LO2 feedline bellows. (Camera E31)

Typical of previous missions, multiple pieces of ice debris were seen falling from the ET/Orbiter umbilicals and along the -Z side of the body flap during SSME ignition through liftoff. No damage to the launch vehicle was noted. (Cameras E1, E4, E5, E18, E19, E31, E34, E40, E52, E63, OTV009, OTV054, OTV063)

An unidentified, dark-colored piece of debris first seen beneath SSME #3 was seen falling aft prior to liftoff (21:22:46.163 UTC). On camera E20, another small unidentified dark-colored piece of debris was seen just aft of SSME #3 just after the LO2 T-0 umbilical disconnect. (Camera E19, E20)

Summary of Significant Events

Multiple pieces of SRB throat plug and/or SRB flame duct debris were seen near the right and left SRBs during liftoff. On cameras E36 and E52, SRB flame duct debris was seen north of the MLP during liftoff (21:22:50.495, 21:22:50.646 UTC). On camera E5, debris that originated near the LSRB flame duct traveled between the two SRB's (21:22:49.709 UTC). Also on camera E5, several pieces of debris were seen near the +Y side of the LSRB (21:22:49.352 UTC) and several pieces of debris were seen coming from the aft skirt area of the RSRB east of the MLP (21:22:50.476, 21:22:50.791 UTC). On camera E20, several pieces of light-colored debris (probably instafoam) were first seen near the RSRB aft skirt before moving eastward at liftoff (21:22:51.6 UTC). None of this debris was seen to contact the launch vehicle. (Cameras E1, E5, E36, E52)

A single piece of unidentified debris was seen traveling in an arc motion over the top of the LO2 TSM during liftoff (21:22:51.192 UTC). (Camera E5)

A white-colored piece of debris was seen traveling upward from near the -Z side of the body flap toward the LSRB aft skirt during liftoff (21:22:53.494 UTC) (Camera OTV061)

A large, light-colored piece of debris was seen in the exhaust cloud after liftoff (21:23:09.310 UTC). This debris was possibly a piece of SRB throat plug or SRB flame duct debris. (Camera E63)

2.2.2 Debris During Ascent

A single piece of light-colored debris (probably ice/frost from the forward LO2 feedline bellows) was seen falling aft along the Orbiter fuselage tiles during liftoff (21:22:51.830 UTC). (Cameras E34, E36)

Multiple pieces of debris, too numerous to count (mostly umbilical ice and RCS paper debris), were seen falling aft of the launch vehicle during ascent. See Table 2.2.2 (A). Umbilical ice and RCS paper debris during ascent has been seen on previous mission films and videos. (Cameras E52, E207, E223, E224)

Summary of Significant Events

| Camera | Time (UTC) | Description |
|-----------------|--|---|
| E52 | 21:23:01.776 | RCS paper debris seen falling aft over left wing |
| E52 | 21:23:04.370 | RCS paper debris seeing falling aft over left wing |
| E52, E223, E224 | 21:23:03.5, 21:23:04.776, 21:23:06.742 | Multiple pieces of umbilical ice seen falling along -Z side of body flap before and after the roll maneuver |
| E52 | 21:23:08.287 | Forward RCS paper debris seen falling aft over right wing |
| E223 | 21:23:04.433, 21:23:12.211 | Multiple pieces of RCS paper debris seen falling aft of the launch vehicle |
| E52 | 21:23:12.204 | Forward RCS paper debris seen falling aft over right wing |
| E207 | 21:23:13.992 | RCS paper debris seen on +Z side of SSME #1 |

Table 2.2.2 (A) RCS Paper and Umbilical Ice Debris during Ascent

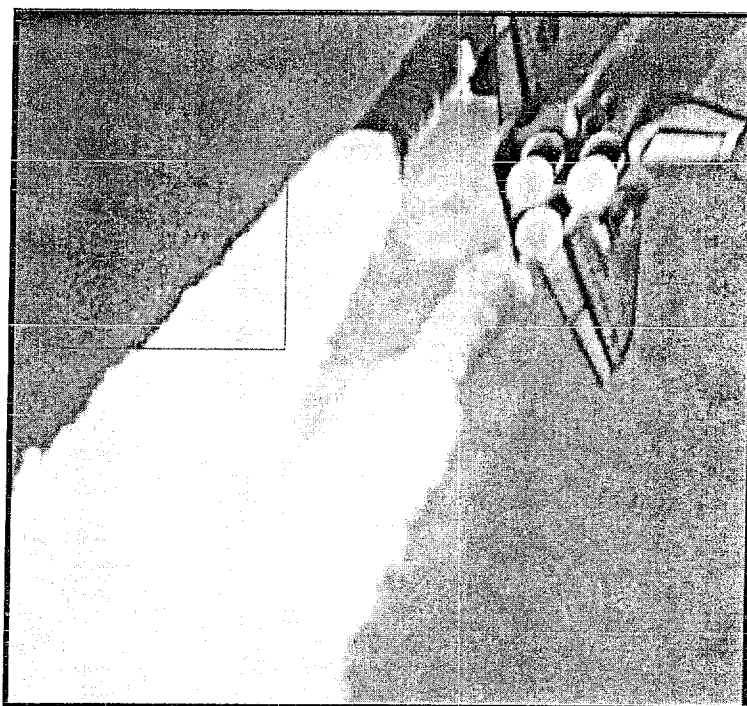


Figure 2.2.2 (A) Spray of Debris Exiting the LSRB Exhaust Plume (Camera E52)

Numerous pieces of debris (in excess of twenty) were seen falling aft from the LSRB exhaust plume near the LSRB aft skirt during early ascent (21:23:06.439 UTC). See Figure 2.2.2 (A). The debris occurred simultaneously on both sides of the LSRB exhaust plume. Approximately two seconds later, a second spray of debris (at least fifteen in number) was again seen in the same location on both sides of the LSRB exhaust plume

Summary of Significant Events

(21:23:08.287 UTC). Although debris exiting the SRB exhaust plumes has been typically seen on previous mission imagery, this event is considered unusual because of the amount (not size) of debris that was visible. (Camera E52)



**Figure 2.2.2 (B) Debris Seen Exiting the SRB Exhaust Plume During Ascent
(Camera E207)**

Other debris was also seen exiting the SRB exhaust plumes late during ascent. The debris exiting the SRB exhaust plumes during late ascent was probably instafoam from the aft end of the SRB's. See Figure 2.2.2 (B). The more dense appearing debris near the time of tail-off, just prior to SRB separation, was probably SRB slag debris. Examples of this debris are provided in Table 2.2.2 (B).

Summary of Significant Events

| Camera | Event Time (UTC) | Description |
|-------------|------------------------------|---|
| E52 | 21:23:04.925 | Debris fell aft along SRB exhaust plume |
| E52 | 21:23:06.439 21:23:08.287 | Spray of debris near LSRB aft skirt |
| E52 | 21:23:09.135 | Debris fell aft along SRB exhaust plume |
| E52 | 21:23:09.165 | Debris near RSRB stiffener rings traveled in -Y direction, then aft |
| E223 | 21:23:13.248 | Debris near LSRB traveled toward body flap |
| E207 | 21:23:22.709 | Debris near LSRB aft skirt |
| E223 | 21:23:45.211 | Debris fell aft along SRB exhaust plume |
| E223 | 21:23:49.189 | Debris fell aft along SRB exhaust plume |
| E223 | 21:23:53.015 | Debris fell aft along SRB exhaust plume |
| KTV4A | 21:23:59.523 | Debris fell aft along SRB exhaust plume |
| E223, KTV4A | 21:24:01.559 | Debris fell aft along SRB exhaust plume |
| E223, KTV4A | 21:24:06.449 | Debris fell aft along SRB exhaust plume |
| E207 | 21:24:11.785 21:24:46.928 | Slag debris fell aft along LSRB exhaust plume |

Table 2.2.2 (B) Debris Seen Exiting SRB Exhaust Plume

2.2.3 Mobile Launch Platform (MLP) Events

The SSME ignition appeared normal except for the unusual flash described above under section 2.1. During SSME start-up, the SSME Mach diamonds formed in the expected sequence (3, 2, 1). The times for the Mach diamond formation given in Table 2.2.3 are from film E19 (Cameras E19, E20, E76, OTV070):

| SSME | Time (UTC) |
|---------|--------------|
| SSME #3 | 21:22:45.704 |
| SSME #2 | 21:22:45.878 |
| SSME #1 | 21:22:46.075 |

Table 2.2.3 SSME Mach Diamond Formation Times

(STS-111 was the second flight using all three of the new Space Shuttle Block II main engines. A comparison of the times between the engine mach diamond formations of the three STS-111 engines was made with the equivalent Mach diamond formation times on

Summary of Significant Events

the previous eight missions. The STS-111 mach diamond formation times were found to be comparable to the previous mission times.)



**Figure 2.2.3 (A) Orange Vapor Seen Forward of SSME Rims Prior to Liftoff
(Camera OTV070)**

Orange vapor (possibly free burning hydrogen) was seen forward of the SSME rims, near the base heat shield, near the trailing edge of the vertical stabilizer, near the drag chute door, and on the $-Z$ side of the body flap, during SSME ignition (21:22:44.021 UTC). See Figure 2.2.3 (A). With the exception of the orange-colored flash described under section 2.1, the orange vapor on the STS-111 films appeared to be similar to those typically seen on previous mission films and videos. (Cameras E2, E18, E20, E76, OTV063, OTV070)

Frost was visible on the edges of the $-Y$ ET GOX vent louver prior to liftoff. Frost on the ET vent louvers has been seen on previous mission videos. (Camera OTV061)

A slight flexing motion of the SSME #2 Dome Mounted Heat Shield (DMHS) was seen during SSME ignition (21:22:45.686 UTC). Flexing of the DMHS during SSME ignition has been seen on previous missions. (Camera OTV070)

Faint, light-orange-colored streaks were seen in the SSME exhaust plumes, possibly debris induced, after SSME ignition and prior to liftoff at the times shown below (Cameras E2, E19, E20, E76):

SSME #1 – 21:22:47.113 UTC

SSME #2 – 21:22:46.851 UTC

SSME #3 – 21:22:47.732, 21:22:47.746, 21:22:47.962 UTC

Summary of Significant Events

Streaks in the SSME exhaust plume prior to liftoff have been seen on previous mission films.

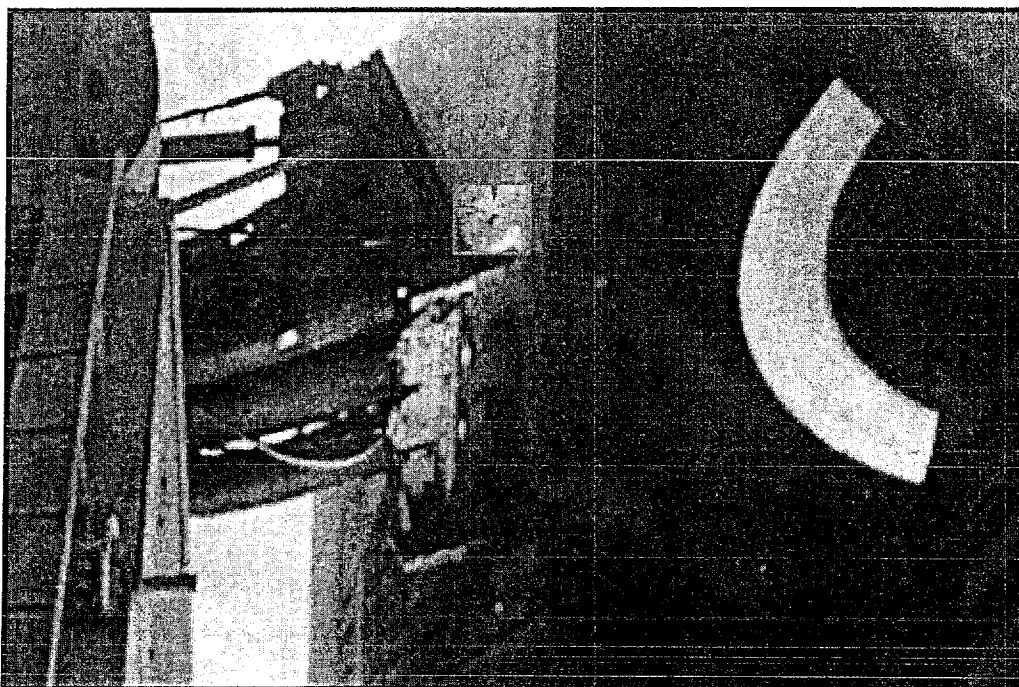
Typical of previous missions, small areas of tile surface coating material erosion were seen on the base of the left RCS stinger, on the base heat shield on the -Z side of SSME #2 near the Dome Mounted Heat Shield (DMHS), on the base heat shield on the -Y side of SSME #2, and on the base heat shield on the +Y side of SSME #3 during SSME ignition. (Cameras E17, E18, E20)

No significant movement of the OMS pod tiles during SSME ignition was detected on the STS-111 camera films. (Cameras E17, E18)

The GH2 vent arm retraction from the ET at liftoff appeared normal (21:22:49.014 UTC). Ice and vapors were seen falling aft along the ET during the vent arm retraction. (Cameras E33, E34, E36, E61, E64). Ice debris was seen falling aft and contacting the LSRB during the GH2 vent arm retraction from the External Tank (21:22:49.739 UTC) (Camera 33). No damage to the LSRB was noted. The GH2 vent arm was seen to contact the deceleration cable near the center position during the downward rotation of the arm during retraction. Positive capture was achieved on the vent line latch. The times of these events were (Camera E39):

21:22:50.481 UTC - GH2 vent line contacted the deceleration cable.

21:22:50.896 UTC - Approximate time of latch-back of the GH2 vent arm.



**Figure 2.2.3 (B) Ground Strap Seen During LO2 TSM T-0 Umbilical Retraction
(Camera E17)**

Summary of Significant Events

A small, dark-colored, object was seen trailing the LO2 TSM T-0 umbilical during retraction (21:22:49.406 UTC). The object appeared to follow the T-0 umbilical toward the LO2 TSM before being lost from view. See Figure 2.2.3 (B). KSC reported that this object was the grounding strap that goes from the LO2 TSM to the Orbiter. Normally the grounding strap is obscured by vapors and is not visible. (Camera E17)

The left and right SRB GN2 purge lines appeared wrapped, upright, and intact until they were obscured by exhaust plumes at 21:22:51.168 UTC (right purge line) and 21:22:50.878 UTC (left purge line). (Cameras E8, E13)

2.2.4 Ascent Events

A large piece of ET/Orbiter umbilical purge barrier material was seen falling aft from the ET / Orbiter umbilical area along the body flap during early ascent (21:23:04.925 UTC). On camera E222, ET/Orbiter umbilical purge barrier material was seen falling aft along the body flap at 21:23:14.206 UTC. ET/Orbiter purge material debris during ascent has been seen on previous mission imagery. (Cameras E52, E222, E223)



Figure 2.3.4 Flare Seen in SSME Exhaust Plume (Camera E222)

Summary of Significant Events

Light-colored flares (possibly debris induced) were seen in the SSME exhaust plumes during ascent on the intermediate and long range tracking camera films and videos. See Figure 2.3.4. (Often on previous mission imagery, debris has been seen contacting the SSME exhaust plume resulting in visible flares. Usually this debris was RCS paper. On STS-26 and STS-101, debris that resulted in very large orange-colored flares was determined to have been tile material.) Examples of flares seen on STS-111 can be seen in Table 2.3.4. Flares in the SSME exhaust plumes have been seen on previous missions films and videos.

| Camera | Time (UTC) | Event |
|-------------|--------------|--|
| E207 | 21:22:57.710 | Flare in SSME exhaust plume |
| E222 | 21:23:15.550 | Flare in SSME exhaust plume |
| E222, KTV4A | 21:23:15.901 | Flare in SSME exhaust plume |
| E222 | 21:23:18.828 | Debris induced flare in SSME exhaust plume |
| E207, KTV4A | 21:23:21.691 | Flare in SSME exhaust plume |
| E222 | 21:23:21.736 | Flare in SSME exhaust plume |
| E223 | 21:23:24.816 | Flare in SSME exhaust plume |
| E223 | 21:23:27.731 | Flare in SSME exhaust plume |
| E223 | 21:23:30.484 | Flare in SSME exhaust plume |
| E207, E222 | 21:23:39.924 | Flare in SSME exhaust plume |
| E223 | 21:23:41.071 | Flare in SSME exhaust Plume |
| E222, KTV4A | 21:23:41.388 | Flare in SSME exhaust plume |
| E207 | 21:23:46.252 | Flare in SSME exhaust plume |
| E207 | 21:23:48.704 | Flare in SSME exhaust plume |

Table 2.3.4 Flares Seen in SSME Exhaust Plumes During Ascent

A bright flash lasting three frames was seen on the Orbiter right wing tip during ascent (21:23:08.287 UTC). This was probably an atmospheric induced event. (Camera E52)

Condensation was observed around the launch vehicle during ascent (21:23:28.6 through 21:23:42.0 UTC). Condensation plumes and condensation streaks off the launch vehicle have been seen on previous mission films and videos. (Camera E207, KTV2, KTV4A, ET212)

Body flap motion typical of that seen on previous missions was seen during ascent (21:23:18.4 - 21:24:05.0 UTC). (Camera E207, ET207)

An orange-colored flash from the early OMS-2 assist burn was seen approximately ten seconds after SRB separation (21:25:03.165 UTC). (Camera E207, ET207)

Summary of Significant Events

2.3 Onboard Photography of the External Tank (ET-114)

2.3.1 35mm Umbilical Well Camera Film (Roll 384)

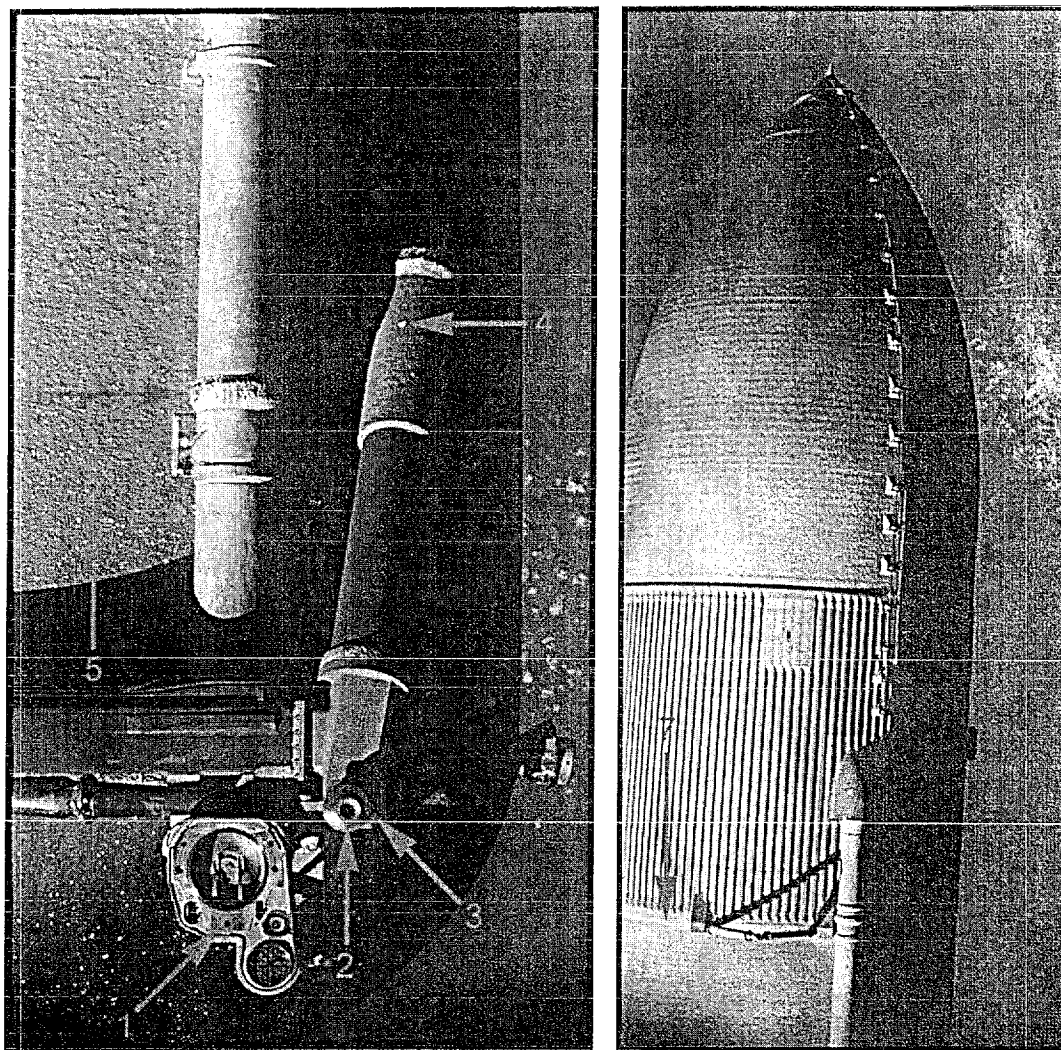


Figure 2.3.1 (A) 35mm Images of the ET during Separation (Frames 11 and 48)

The face of the LO2 umbilical carrier plate appeared to be in excellent condition (no indication of damaged or missing lightning contact strips was detected). See Figure 2.3.1 (A), annotation 1.

The separation bolt between the ET and the aft end of the Orbiter (EO-3 fitting near the liquid oxygen umbilical) appeared to be retracted. See Figure 2.3.1 (A), annotation 2.

Typical ablation and divoting of the TPS on the vertical section of the +Y electric cable tray adjacent to the LO2 umbilical was detected.

Summary of Significant Events

The red-colored purge seal on the EO-3 ball joint fitting was in place. See Figure 2.3.1 (A), annotation 3.

The TPS on the +Y thrust strut appeared to be in good condition. One small area of TPS erosion was noted on the forward end of the +Y thrust strut. See Figure 2.3.1 (A), annotation 4.

Typical of previous missions, small “popcorn” divots were seen on the aft LH2 tank TPS forward of the crossbeam. See Figure 2.3.1 (A), annotation 5.

Minor TPS abrasion on the LO2 feedline brackets was visible. See Figure 2.3.1 (A), annotation 6. As typically seen, a white-colored line (probably frost) was seen on the aft edge of the aft LO2 feedline bellows.

The LH2 tank-to-intertank close-out flange appeared to be in good condition. See Figure 2.3.1 (A), annotation 7. Two small, light-colored TPS erosion marks were seen near the +Y leg of the forward bipod on the LH2 tank-to-intertank close-out. No exposed substrate material was noted. The bipod jack pad close-outs appeared to be in good condition.

One small erosion mark was seen on the LH2 tank TPS just aft of the forward bipod.

One small erosion mark was noted on an intertank stringer head near the forward end of the LO2 feedline in the -Y direction from the LO2 feedline bellows.

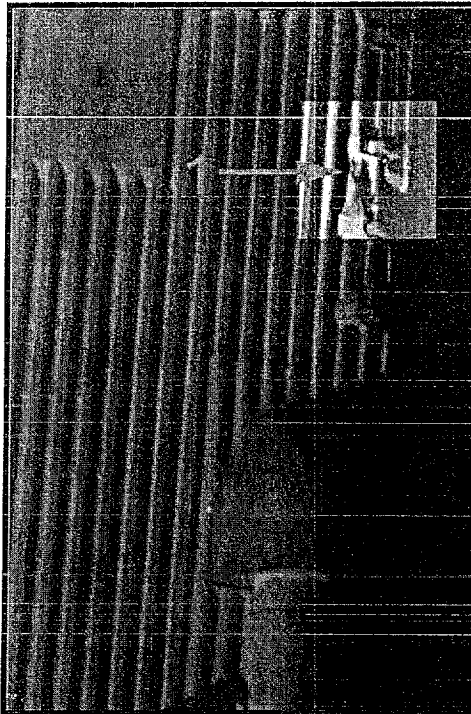


Figure 2.3.1 (B) 35mm Image of TPS Erosion on the ET Intertank (Frame 39)

Summary of Significant Events

One TPS divot was observed on an intertank stringer head near the GO2 press / line ramp at station xt -897. The divot was at least six inches long and appeared to have exposed primed substrate. KSC reported that this was an area of the intertank that was not sanded or vented. See Figure 2.3.1 (B), annotation 1.

The LO2 tank TPS and the nose of the ET appeared to be in good condition.

Notes: On STS-111, the (old) Nikon F4 35mm umbilical camera with the 55mm lens and Kodak color positive film was flown. Coverage included the aft end of the ET and forward along the +Z side of the ET to the tip of the ET. Shadows from the late afternoon Sun limited the 35mm umbilical camera views in the +Y direction of the ET LO2 feedline. The LO2 pressurization and electrical cable lines were obscured by shadow. The +Y ET Thrust Panel was not imaged.

Fifty-six frames were acquired with the 35mm umbilical camera. The images were excellent quality except for the areas obscured by shadow. The focus is good. The exposure on the Sun lit portions of the ET is good.

2.3.2 16mm Umbilical Well Camera Films with the 5mm and 10mm Lenses (FL101 and FL102)

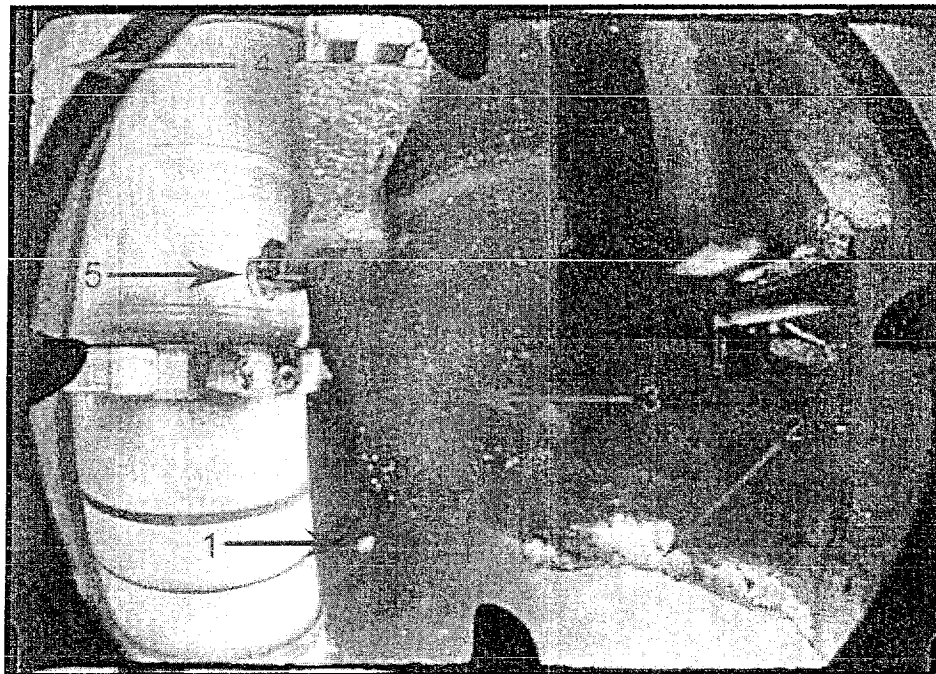


Figure 2.3.2 (A) 16mm Umbilical Well Camera SRB Separation Image

Summary of Significant Events

SRB Separation:

The LSRB separation appeared normal on the 16mm umbilical well camera films (recorded through the 5mm and 10 mm lenses).

Numerous light-colored pieces of debris (insulation), and dark debris (charred insulation) were seen throughout the SRB separation film sequence. See Figure 2.3.2 (A), annotation 1. Typical ablation and charring of the ET/Orbiter LH2 umbilical electric cable tray and the aft surface of the -Y upper strut fairing were seen prior to SRB separation. See Figure 2.3.2 (A), annotation 2. Numerous irregularly shaped pieces of debris (charred insulation) were noted near the base of the LSRB electric cable tray prior to SRB separation. Typical, small "pop corn" divots were seen on the ET aft dome. See Figure 2.3.2 (A), annotation 3.

A long, rectangular-shaped piece of orange-colored umbilical purge barrier material was visible on the left side of the camera view. See Figure 2.3.2 (A), annotation 4.

A slight rebound motion (twang) of the EB9 interface at the SRB / ET upper aft stabilization strut was visible during the LSRB separation. See Figure 2.3.2 (A), annotation 5. This motion was compared to the same umbilical well camera view from STS-109. An identical motion was also observed on the STS-109 film.

No anomalies were seen on the left and right SRB nose caps during SRB separation.

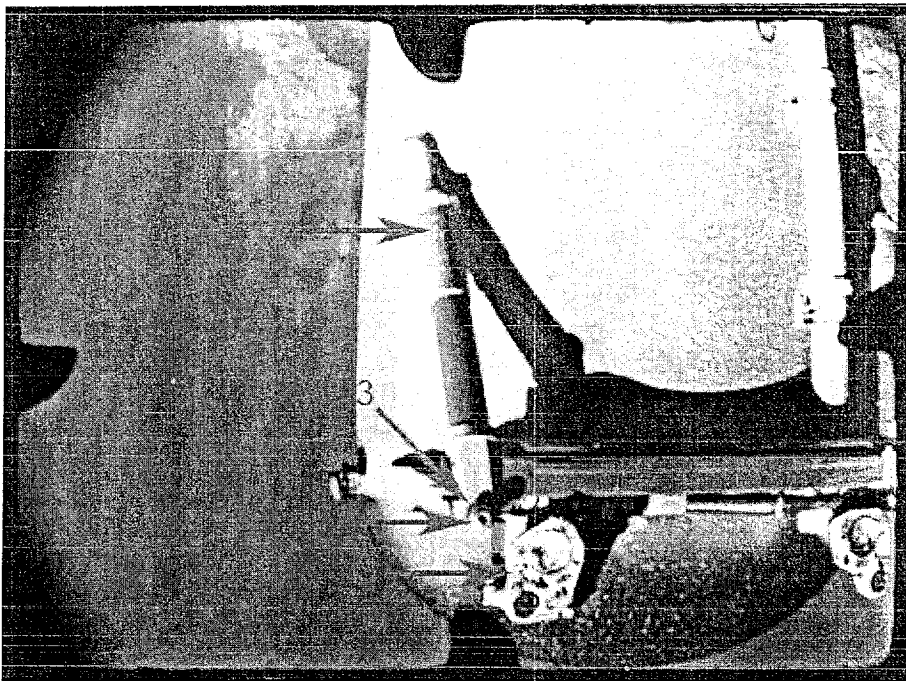


Figure 2.3.2 (B) 16mm Umbilical Well Camera ET Separation Image

Summary of Significant Events

ET Separation:

The ET separation from the Orbiter appeared normal (although initially, the view was dark because of the shadow of the Orbiter from the late afternoon Sun).

A piece of white-colored debris (frozen hydrogen) was seen striking the ET / Orbiter aft attach brace. No damage to the attach brace was noted.

After separation, the ET gradually began tilting in a +Y direction (on STS-110, a tilt in the -Y direction was seen). Boeing Integrated Ascent GN&C personnel stated that the +Y tilt was consistent with the residual angular velocity of the STS-111 Orbiter due to the new OI-29 alpha-beta management and was the expected nominal behavior for STS-111.

Typical vapor and multiple light-colored pieces of debris were seen after the umbilical separation. No anomalies were noted on the face of the LH2 umbilical after ET separation. See Figure 2.3.2 (B), annotation 1. As typically seen on previous missions, frozen hydrogen was visible on the orifice of the LH2 17 inch connect. A long, thin, white-colored piece of debris (frozen hydrogen) with a curved shape was visible on the 16mm umbilical well camera views prior to when the ET began to move away from the Orbiter.

The separation bolt between the ET and the aft end of the Orbiter (EO-2 fitting near the liquid hydrogen umbilical) appeared to be retracted. See Figure 2.3.2 (B), annotation 2. The red-colored purge seal on the EO-2 ball joint fitting was in place. See Figure 2.3.2 (B), annotation 3. Small divots / TPS erosion were seen on the forward flange of the -Y thrust strut. See Figure 2.3.2 (B), annotation 4. A shallow, triangular-shaped piece of the TPS surface coating material was missing on the forward end of the -Y thrust strut. Otherwise, the TPS covering the length of the -Y thrust strut appeared to be in good condition.

Two small divots were seen under the forward bipod on the LH2 tank-to-intertank close-out flange.

The LH2 tank, the intertank, and the ET nose TPS appeared to be in good condition on the 16mm camera views. The acro heating marks on the intertank and the BSM burn scars on the LO2 tank were typical.

Notes: Both of the 16mm umbilical camera films were excellent quality. The exposure and focus was good on both films. Timing data was not present on the FL101 film (5mm lens). Timing data was present on the FL102 umbilical well camera film (10mm lens).

Summary of Significant Events

2.3.3 35mm Crew Handheld Film (Roll 337)

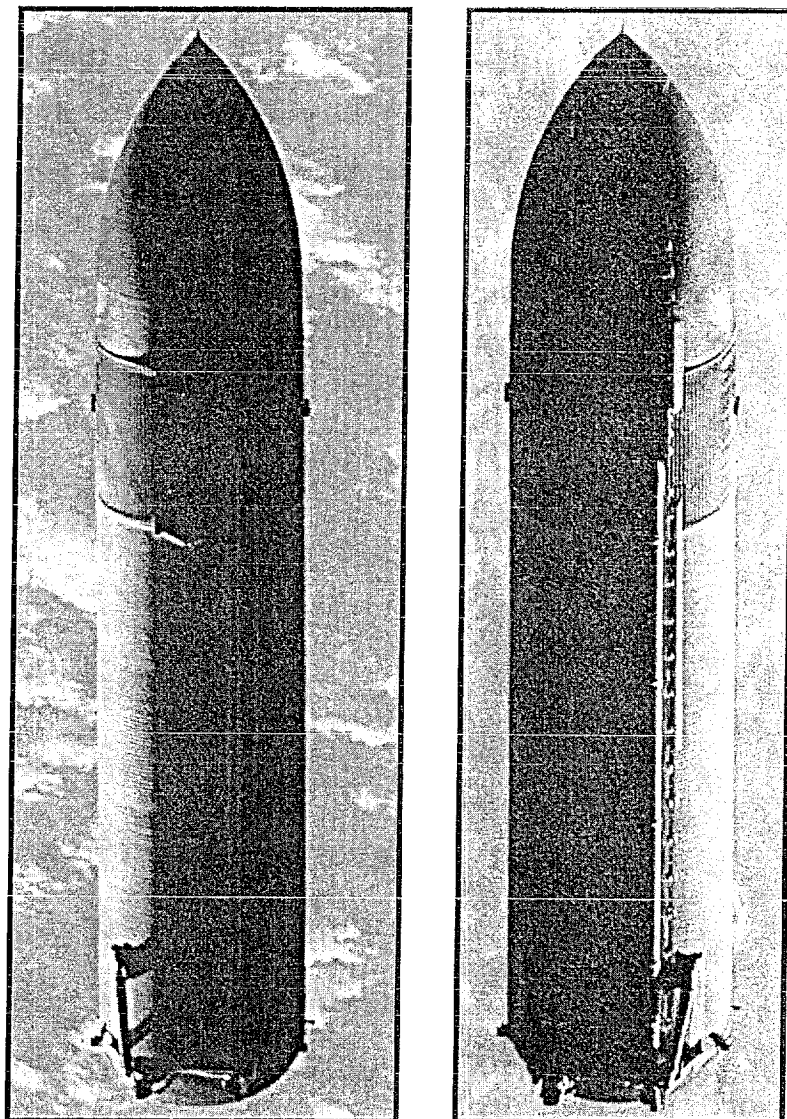


Figure 2.3.3 Handheld Images of the External Tank (Frames 5 and 10)

No anomalous or unusual observations were noted on the handheld film views. The analysis of the views was hindered because of the extensive shadows caused by the position of the ET relative to the late afternoon Sun. Eventually all sides of the ET, were acquired as the ET rolled around its center of mass before the ET disappeared across the sunset terminator. The overall ET TPS including the +Y and -Y ET thrust panels appeared to be in good condition on the handheld film views. No venting from the ET intertank gaseous hydrogen vent or the aft ET umbilicals was seen.

The astronauts performed a manual pitch maneuver from the heads-up position to bring the ET into view in the Orbiter overhead windows for the handheld photography. The

Summary of Significant Events

first picture was taken at 14.4 minutes MET using the handheld Nikon F5 camera with a 400 mm lens. The distance of the ET was calculated to be approximately 1.4 km's on the first photographic frame acquired. A total of thirty-four pictures of the ET were obtained. Timing data is present on the film.

2.3.4 Crew Handheld Video

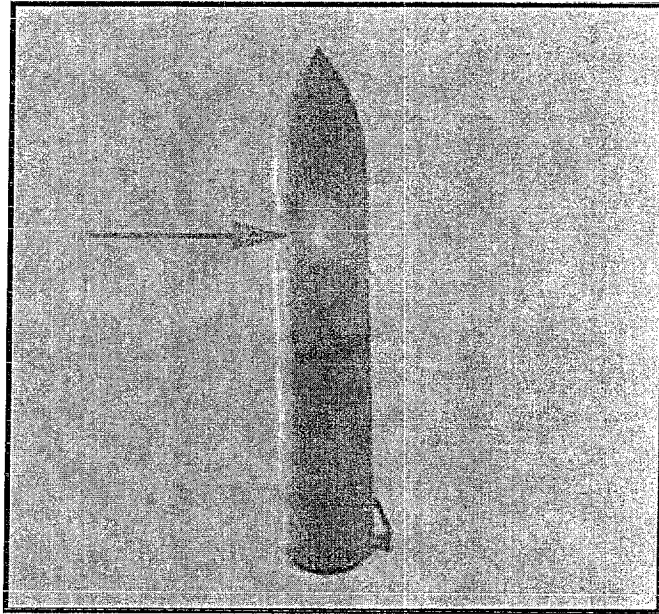


Figure 2.3.4 View of ET Venting After Separation

The astronauts acquired 8.3 minutes of handheld video of the ET on STS-111. Vapors coming from the ET intertank vent were noted. See Figure 2.3.4. Vapors coming from the ET intertank after separation have been seen on previous mission videos. No timing data was present on the video.

Summary of Significant Events

2.4 Landing Timing Events

The time codes from videos were used to identify specific events during the screening process. The STS-111 EAFB landing event times are provided in Table 2.4.

| Event | Time (UTC) | Camera |
|--|------------------|--------|
| Left Main Gear Door Opening | 170:17:57:24.004 | LRO1 |
| Nose Gear Door Opening | 170:17:57:24.037 | LRO1 |
| Right Main Gear Door Opening | 170:17:57:24.171 | LRO1 |
| Right Main Gear Tire Touchdown | 170:17:57:41.288 | LRO1 |
| Left Main Gear Tire Touchdown | 170:17:57:41.321 | LRO1 |
| Drag Chute Initiation | 170:17:57:44.941 | DTV2 |
| Pilot Chute at Full Inflation | 170:17:57:45.742 | DTV1 |
| Bag Release | 170:17:57:46.410 | DTV1 |
| Drag Chute Inflation in Reefed Configuration | 170:17:57:47.277 | DTV1 |
| Drag Chute Initiation in Disreefed Configuration | 170:17:57:51.014 | DTV1 |
| Nose Gear Touchdown | 170:17:57:52.382 | DTV1 |
| Drag Chute Release | 170:17:58:22.979 | DTV1 |
| Wheel Stop | 170:17:58:44.668 | DTV1 |

Table 2.4 Landing Event Times

2.5 Landing Sink Rate Analysis

Image data from the EL1008 35mm motion picture camera on runway 22 at Edwards Air Force Base was used to determine the landing sink rate for STS-111. This camera has a 100mm lens and is located near the northeast end of the runway. (This view is considerably different from the nominal camera view used to determine sink rate for landings at Kennedy Space Center, a view which is aimed straight down the runway.) The sink rate of the orbiter main gear was measured over the final second prior to touchdown of the right main gear. Data points defining the top and bottom of the right main gear tires were collected on every frame (100 frames for each of the main gear). The distance from the top and bottom of the right main gear tire was used to determine a scaling factor. The height of each gear above the runway was calculated by the vertical difference between the bottom of the tires and the corresponding ground point. An assumption was made that the line of sight of the camera was parallel to the horizon and that the error in picking the ground points on the runway was small.

Summary of Significant Events

The sink rate data for STS-111 for the main gear can be seen in Table 2.5 for the last second, the last half second, and the last one-quarter second prior to touch down. The trends for the main gear sink rate for these same times are shown in Figure 2.5.

| Time Prior to Touchdown | Main Gear Midpoint Sink Rate | Estimated Error (1 σ) |
|-------------------------|------------------------------|-------------------------------|
| 1.00 Sec. | 3.0 ft/sec | +/- 0.2 ft/sec |
| 0.50 Sec. | 3.3 ft/sec | +/- 0.2 ft/sec |
| 0.25 Sec. | 3.4 ft/sec | +/- 0.5 ft/sec |

Table 2.5 Main Gear Midpoint Landing Sink Rate

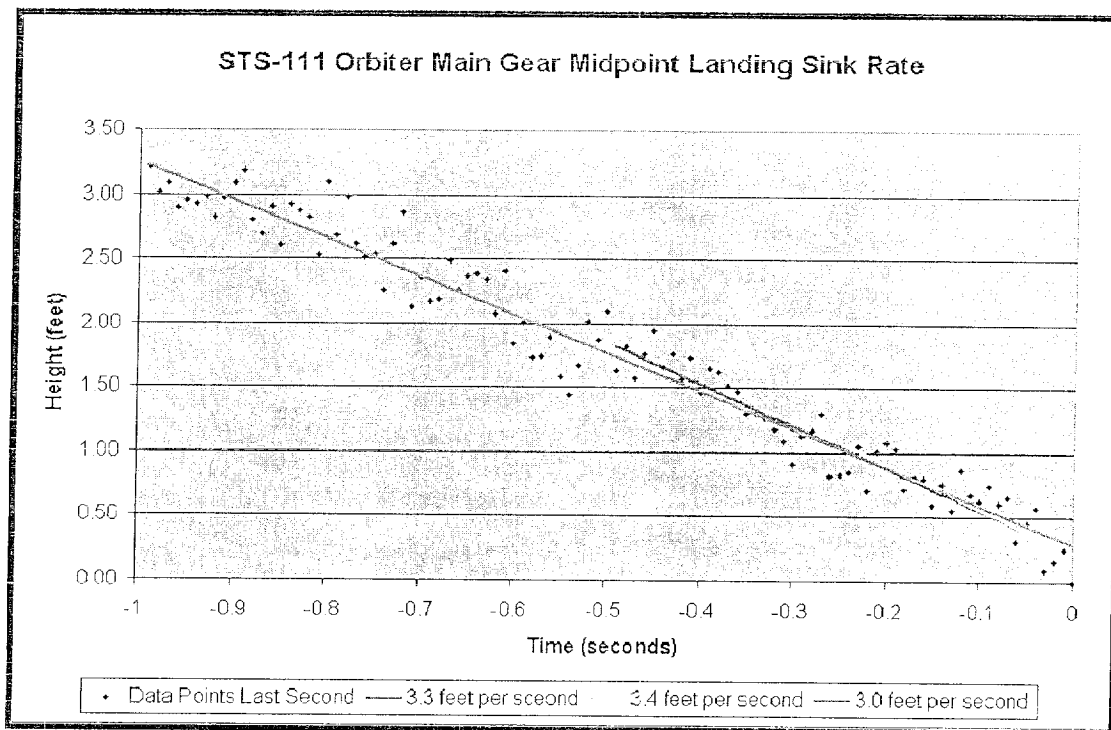


Figure 2.5 Main Gear Midpoint Landing Sink Rate

The maximum allowable main gear sink rate values are 9.6 feet/second for a 212,000 lb. vehicle and 6.0 feet/second for a 240,000 lb. vehicle. The landing weight of the STS-111 vehicle was reported to be 220,173 lbs.

Summary of Significant Events

2.6 Other

2.6.1 Normal Events

Normal events observed included:

- elevon motion prior to liftoff
- ice / frost on SSME purge drain-line vents
- RCS paper debris from SSME ignition through liftoff
- ET twang
- ice and vapor from the LO2 and LH2 TSM T-0 umbilicals prior to and after disconnect
- multiple pieces of ET/Orbiter umbilical ice debris falling along the body flap during liftoff
- vapor off the SRB stiffener rings
- acoustic waves in the exhaust cloud during liftoff
- multiple pieces of debris in the exhaust cloud (including water baffle material) after liftoff
- ET aft dome outgassing and charring of the ET aft dome during ascent
- roll maneuver
- expansion waves
- linear optical effects
- recirculation
- SRB plume brightening
- SRB slag debris before, during and after SRB separation

2.6.2 Normal Pad Events

Normal pad events observed included:

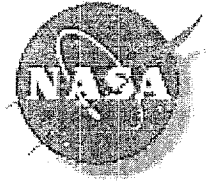
- hydrogen burn igniter operation
- FSS and MLP deluge water activation
- sound suppression system water operation
- TSM T-0 umbilicals disconnect and retraction
- LH2 and LO2 TSM door closure

Summary of Significant Events

- GH2 vent arm retraction
- Small pieces of dark debris (possibly paint chips) from the LO2 TSM prior to liftoff

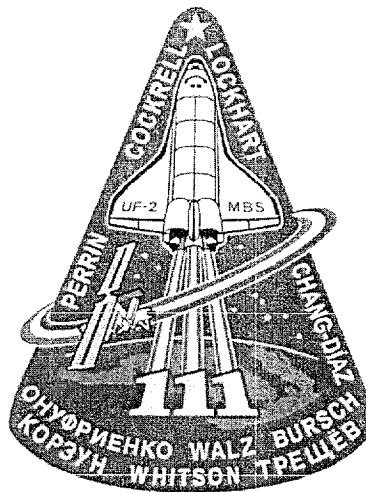
APPENDIX B. MSFC PHOTOGRAPHIC ANALYSIS SUMMARY

The MSFC Report can be accessed on their Engineering Photographic Analysis website at <https://photo4.msfc.nasa.gov/>.



Space Shuttle Mission STS-111

Engineering Photographic Analysis Summary Report Marshall Space Flight Center



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July 8, 2002
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Engineering Photographic Analysis Report for STS-111

Launch of the one hundred-tenth Space Shuttle mission STS-111, the eighteenth flight of the Orbiter Endeavour (OV-105), occurred June 5, 2002 at 4:20 CDT PM from launch complex 39-A Kennedy Space Center (KSC), Florida. Launch time was reported as 156:21:22:49.008 Universal Coordinated Time (UTC) by the MSFC Flight Evaluation Team.



STS-111 Intercenter Consolidated Film/Video Launch+4 Day Report:

The Intercenter Consolidated Film/Video Launch+4 Day Report, June 12, 2002, reported three out-of-family conditions. The report is available on the MSFC Engineering Photographic Analysis website.

Photographic Analysis Website:

Further information concerning photographic analysis of this and previous space shuttle missions is available on the MSFC Engineering Photographic Analysis website at URL:

<http://photo4.msfc.nasa.gov/STS/sts111/sts111.html>

Information available on the MSFC Engineering Photographic Analysis website includes:

- Photographic Acquisition Disposition Document (PADD),
- Individual camera status and assessments,
- Movies and annotated images of notable observations,
- External Tank 35mm Still Camera imagery, and
- Photographic Analysis Mission Summary Report (PDF format).

Photographic Coverage:

Photographic and video coverage has been evaluated to determine proper operation of the flight hardware. Video and high-speed film cameras providing this coverage are located on the fixed service structure (FSS), mobile launch platform (MLP), perimeter sites, Eastern Test Range tracking sites and onboard the vehicle.

Seventy-three engineering photographic products consisting of launch video, ground-based engineering films and onboard film were received and reviewed at MSFC. Camera coverage received at MSFC for STS-111 is illustrated in the following table.

| | 16mm | 35mm | Video |
|-----------|------|------|-------|
| MLP | 19 | 0 | 4 |
| FSS | 6 | 0 | 3 |
| Perimeter | 0 | 9 | 6 |
| Tracking | 0 | 10 | 11 |
| Onboard | 2 | 2 | 1 |
| Other | 0 | 0 | 0 |
| Totals | 27 | 21 | 25 |

Table 1. STS-111 Camera Coverage

Atmospheric haze degraded the quality of images in video cameras ET204, ET208, ET212, and ET213 and in film cameras E204, E208, E212, E213, E220, and E223. Video camera TV13 occasionally loses focus. Video cameras OTV041 and OTV048 have poor exposure, limiting their engineering value.

Film camera E9 appears to slow down just after liftoff. Foreign objects in film camera E204 obscure part of image. The timing display in E205 is occasionally incorrect. Film camera E224 loses track of the vehicle in clouds.

T-Zero Timing:

T-Zero times are regularly determined from MLP cameras that view the SRB Holddown posts, without doghouse covers, M-1, M-2, M-5, and M-6. These cameras, listed below with their corresponding Holddown Post, record the explosive bolt combustion products.

| Holddown Post | Camera | Time (UTC) |
|----------------------|---------------|-------------------|
| M-1 | E9 | 156:21:22:49.015 |
| M-2 | E8 | 156:21:22:49.016 |
| M-5 | E12 | 156:21:22:49.014 |
| M-6 | E13 | 156:21:22:49.015 |

Table 2. STS-111 T-0 Timing

SRB Separation Timing:

SRB separation time, as recorded by observations of the BSM combustion products from long-range high speed film camera E207, occurred at 156:21:24:52.901 UTC.

Anomalous Events:

No anomalous events were observed in launch film or video reviewed at MSFC.

Out-of-Family Observations:

A reddish-orange flash was noted in SSME #1 plume at 21:22:45.538 UTC, 2.846 seconds after ignition. This item is listed in the Intercenter Consolidated Film/Video Launch+4 Day Report.

Typically, reddish-orange free burning Hydrogen flashes are observed just after fuel lead during SSME ignition. This particular flash occurred as flow entrainment is being established and appears to initiate from a disturbance inside SSME #1 nozzle. A bulge in the plume, Figure 1, was observed in the frame just prior to the flash. Also, a band-like area of flow separation was noted as this event initiated, Figure 2.

SSME Project Office reported no concerns with this plume flash after reviewing available data.

Film Camera E2: SSME#1 Plume Flash

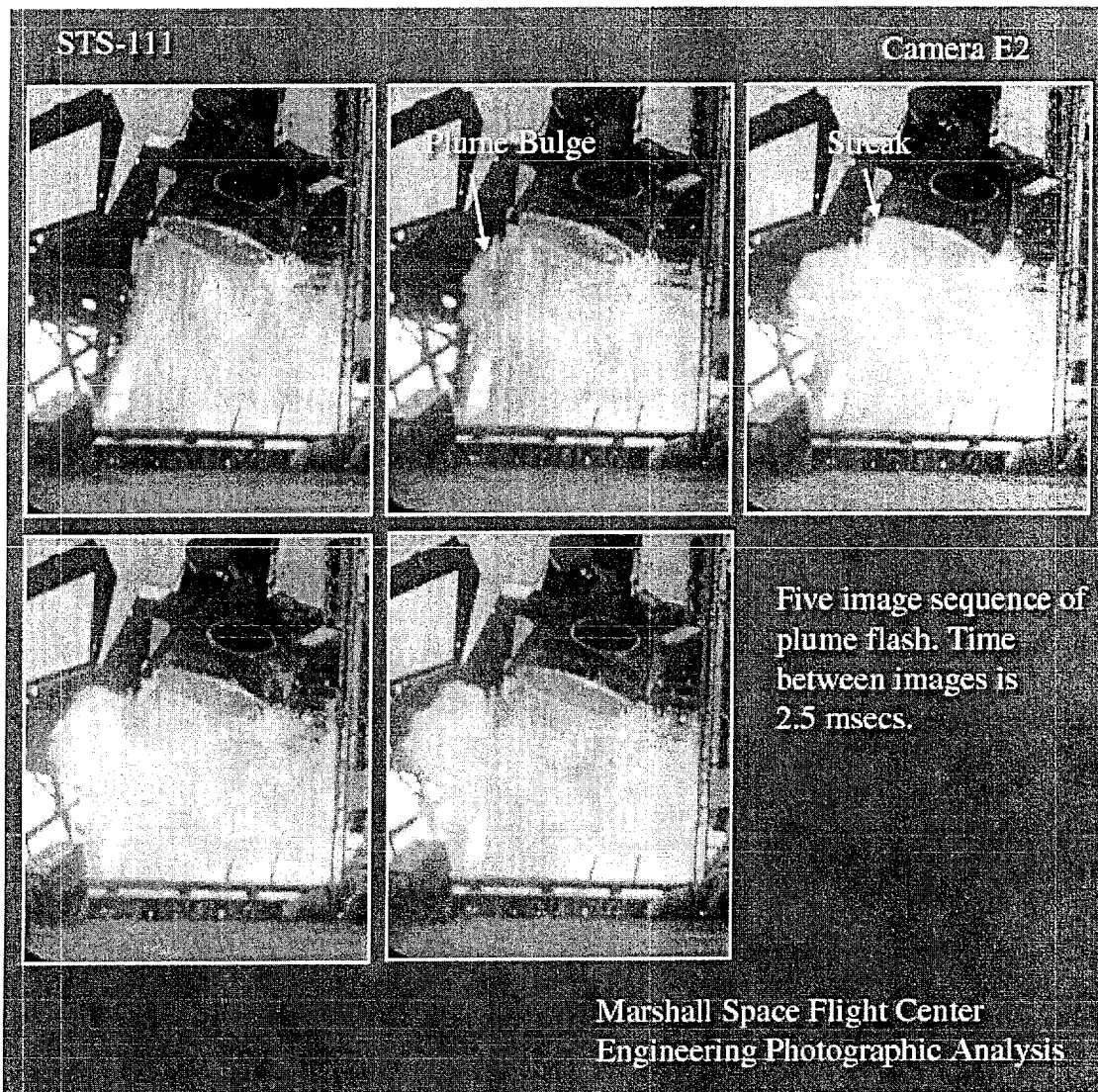


Figure 1. E2: SSME#1 Plume Flash Sequence

Film Camera E20: SSME#1 Plume Flash

Shown below are a sequence of images that illustrate the flow separation characteristics that initiate the plume flash event in SSME#1.

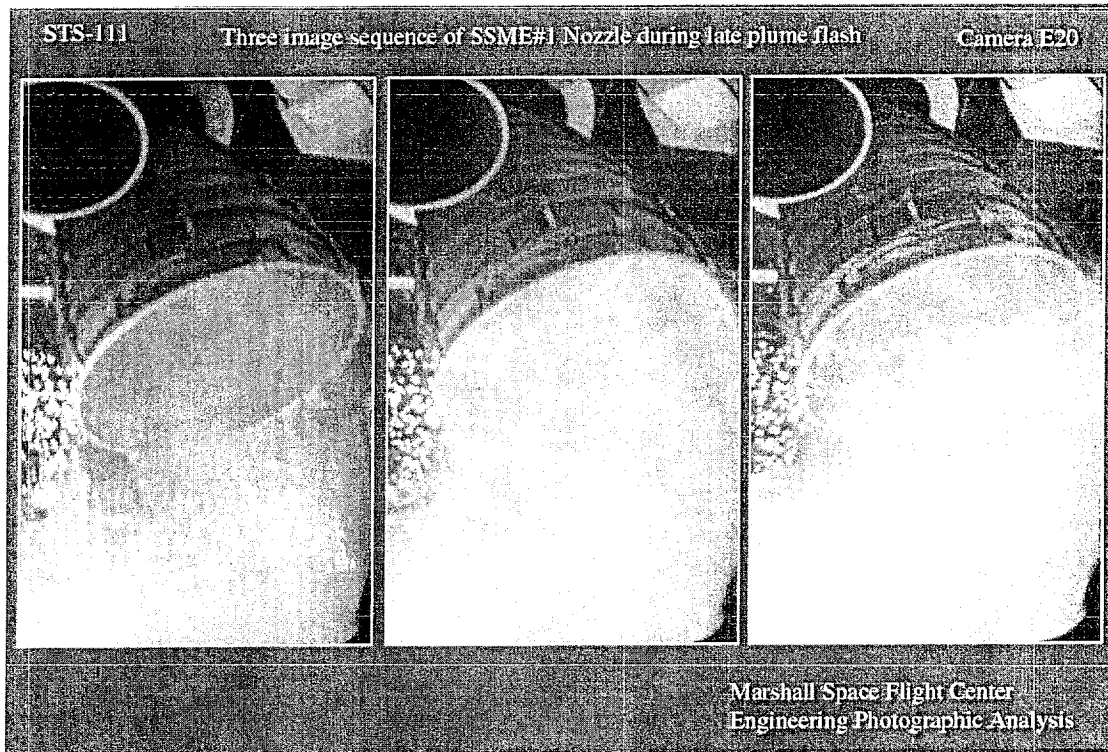


Figure 2. E20: SSME#1 Plume Flash Sequence

Film Camera E2: STS-111 and STS-110 SSME#1 Plume Flash Comparison

Shown below are a sequence of images that compare apparently similar plume flash events in SSME#1 from missions STS-111 and STS-110. Similarities in these plume flash events include: a bulge in the plume, followed by an observable streak in the middle frame, and a noticeable flash resembling free burning hydrogen in the final frame.

The plume flash event in STS-110 was timed at 20:44:15.605 UTC, 2.906 seconds after SSME#1 engine start. The plume flash event in STS-110 was timed at 21:22:45.538 UTC, 2.846 seconds after SSME#1 engine start.

STS-110 and STS-111 are flights having a full Block II engine cluster.

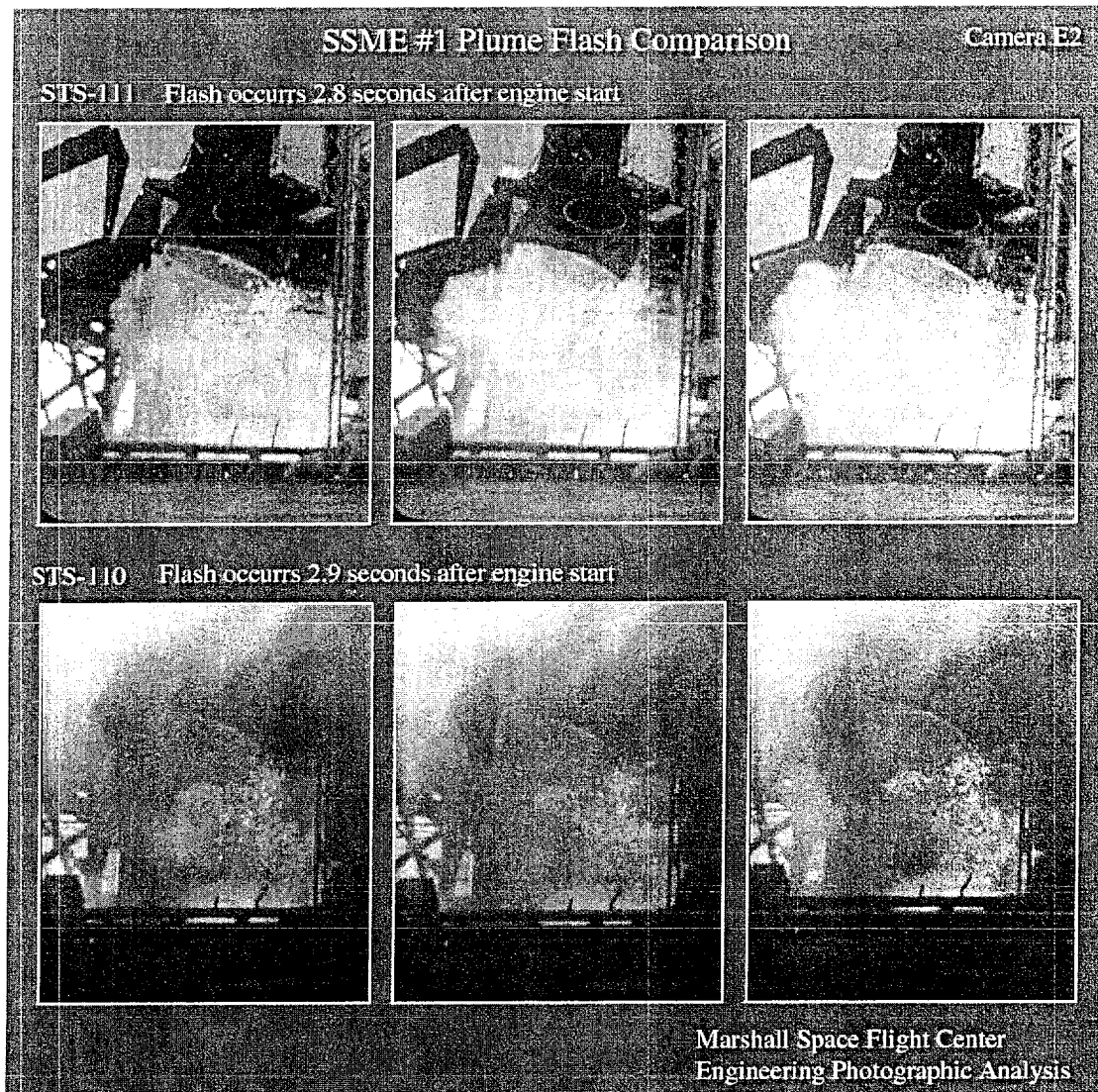


Figure 3. E2: STS-111 and STS-110 SSME#1 Plume Flash Comparison Sequence

Film Camera E52: SSME#1 Plume Flash

Shown below is a sequence of images illustrating the extent of the flash.

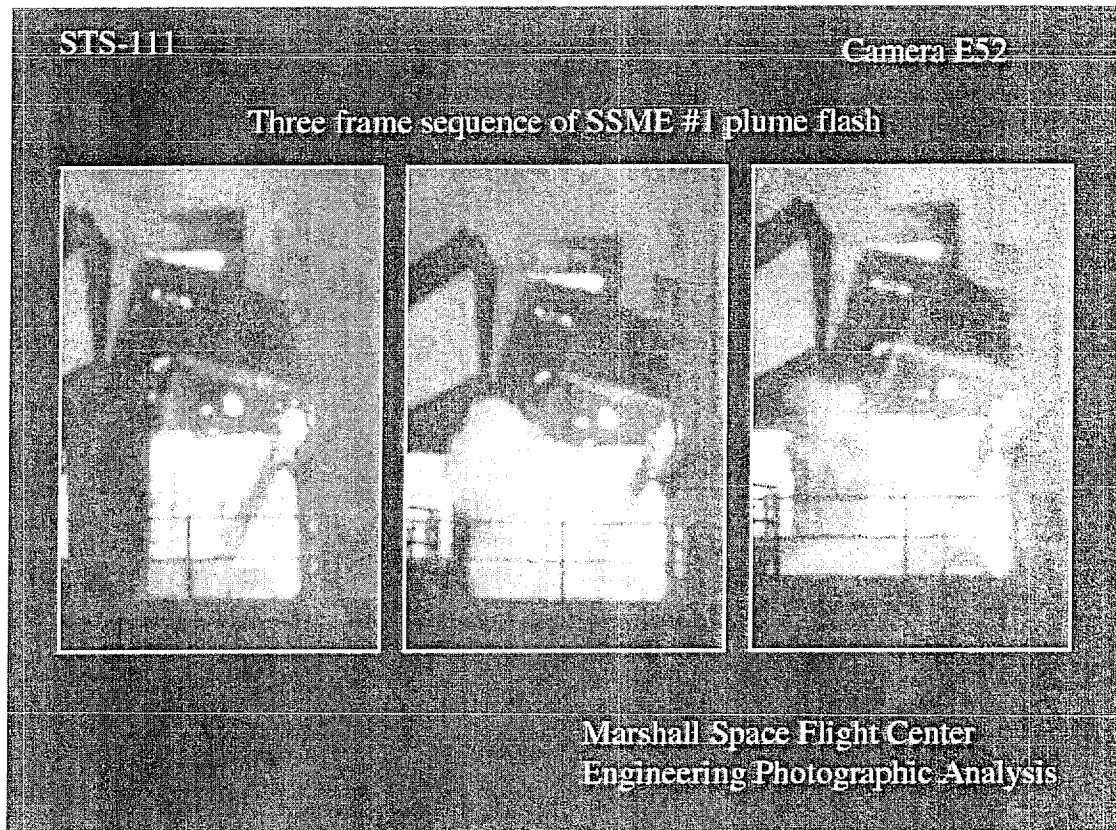


Figure 4. E52: SSME#1 Plume Flash Sequence

Film Camera OTV070: SSME#1 Plume Flash

The images below compare a nominal plume for SSME#1 with the observed plume flash.

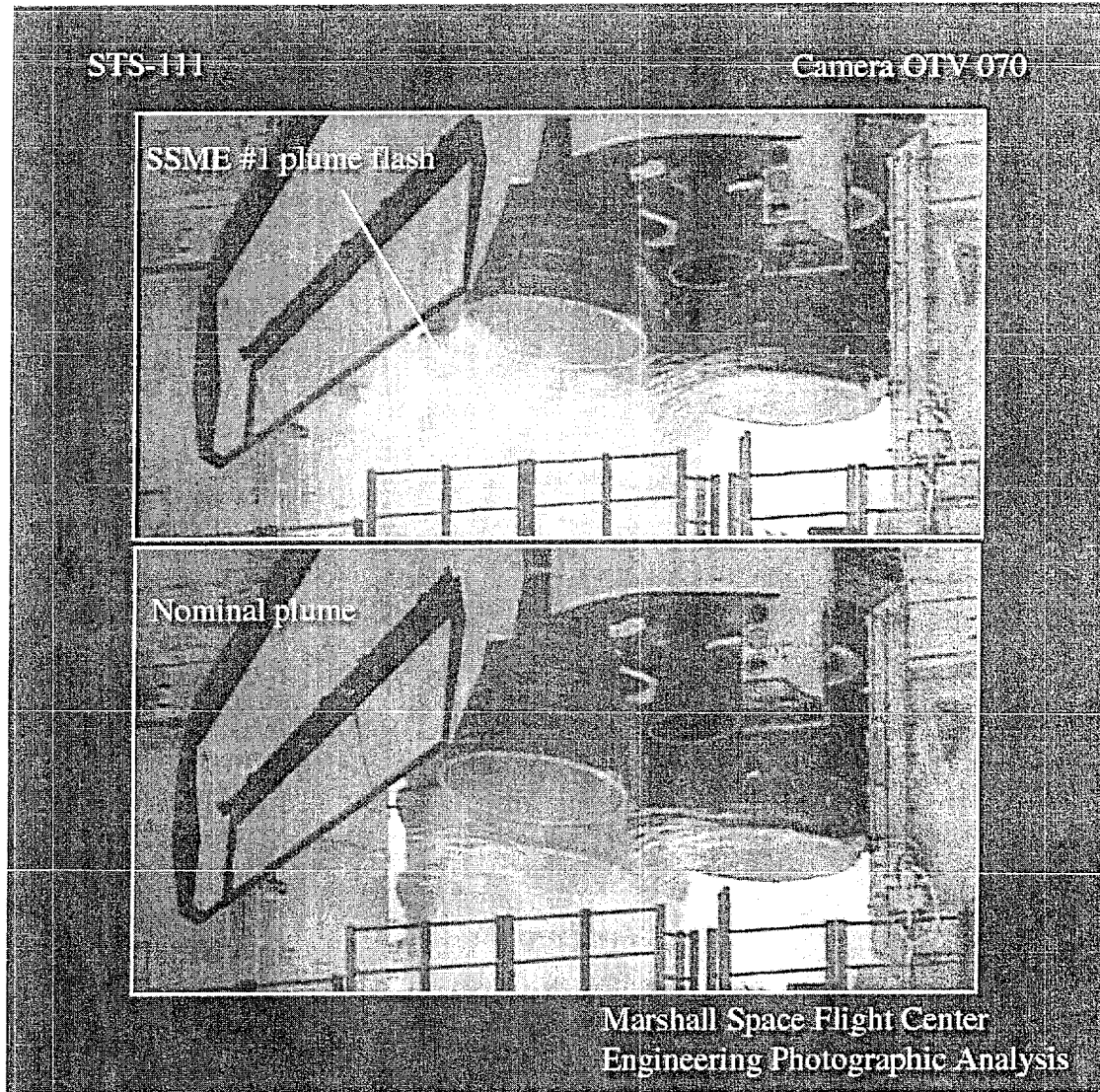


Figure 5. OTV070: SSME#1 Plume Flash and Nominal Plume

Video Camera Montage: SSME#1 Plume Flash

The images below compare a nominal plume for SSME#1 with the observed plume flash from three separate video cameras.

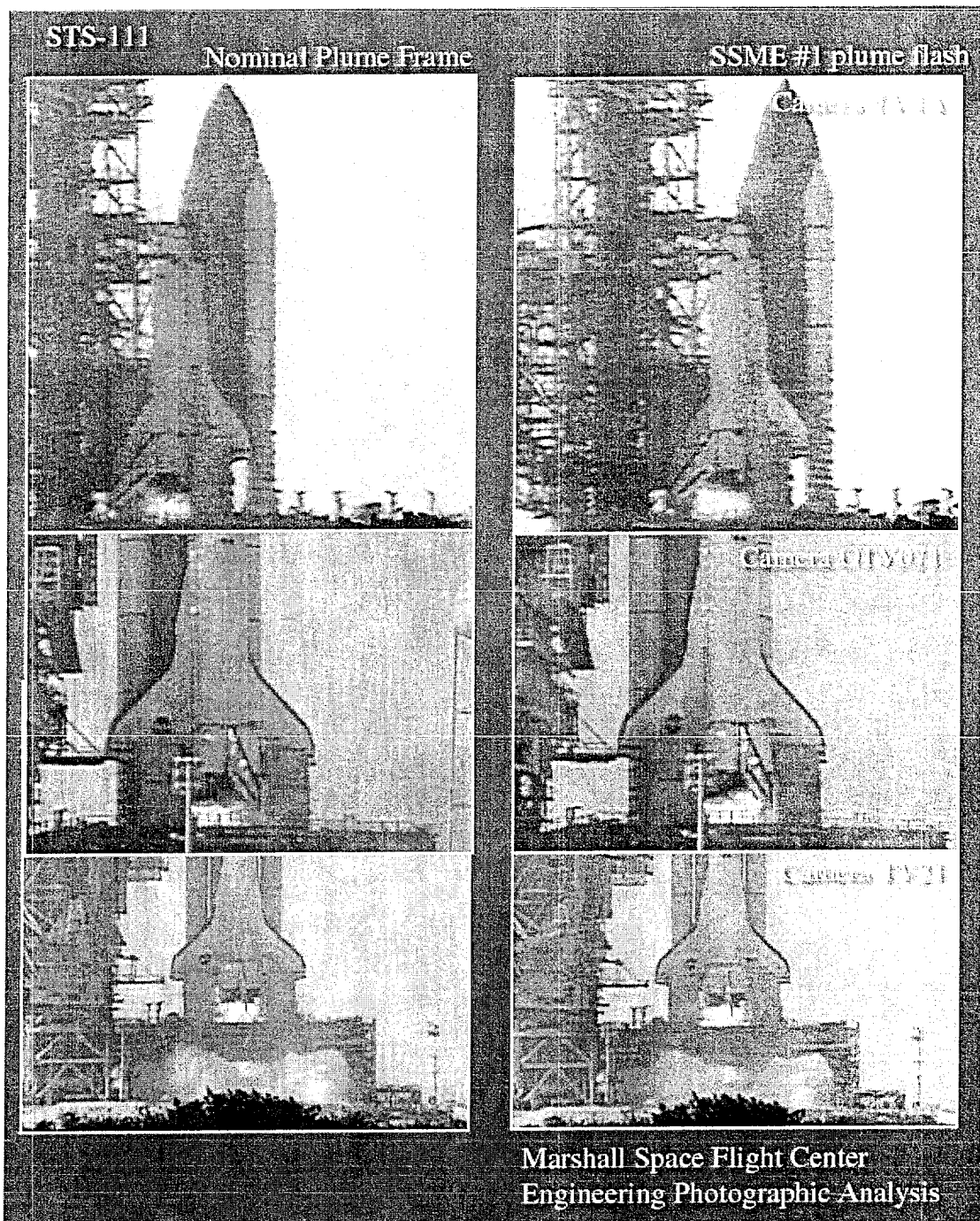


Figure 6. Video Camera Montage: SSME#1 Plume Flash

Video Movies of SSME#1 Plume Flash Available on Website:

Movies illustrating selected film and video camera views of the SSME#1 plume flash were created and made available on the website.



Figure 7. E19: SSME#1 Plume Flash Movie



Figure 9. E20: SSME#1 Plume Flash Movie

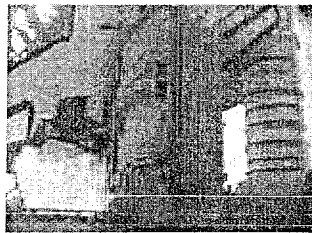


Figure 8. E2: SSME#1 Plume Flash Movie

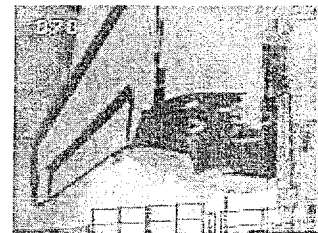


Figure 10. OTV070: Annotated Movie of
SSME#1 Plume Flash

Observations:

Film Camera E20: Frost on SSME#2 Nozzle Prior to Ignition

Frost was observed on SSME#2 Nozzle prior to SSME ignition.



Figure 11. E20: Frost on SSME#2 Nozzle Prior to Ignition

Video Camera OTV070: Free Burning Hydrogen

Free burning Hydrogen was observed in the vicinity of the drag chute door and vertical stabilizer. Free burning Hydrogen has previously been observed at SSME startup in these areas.

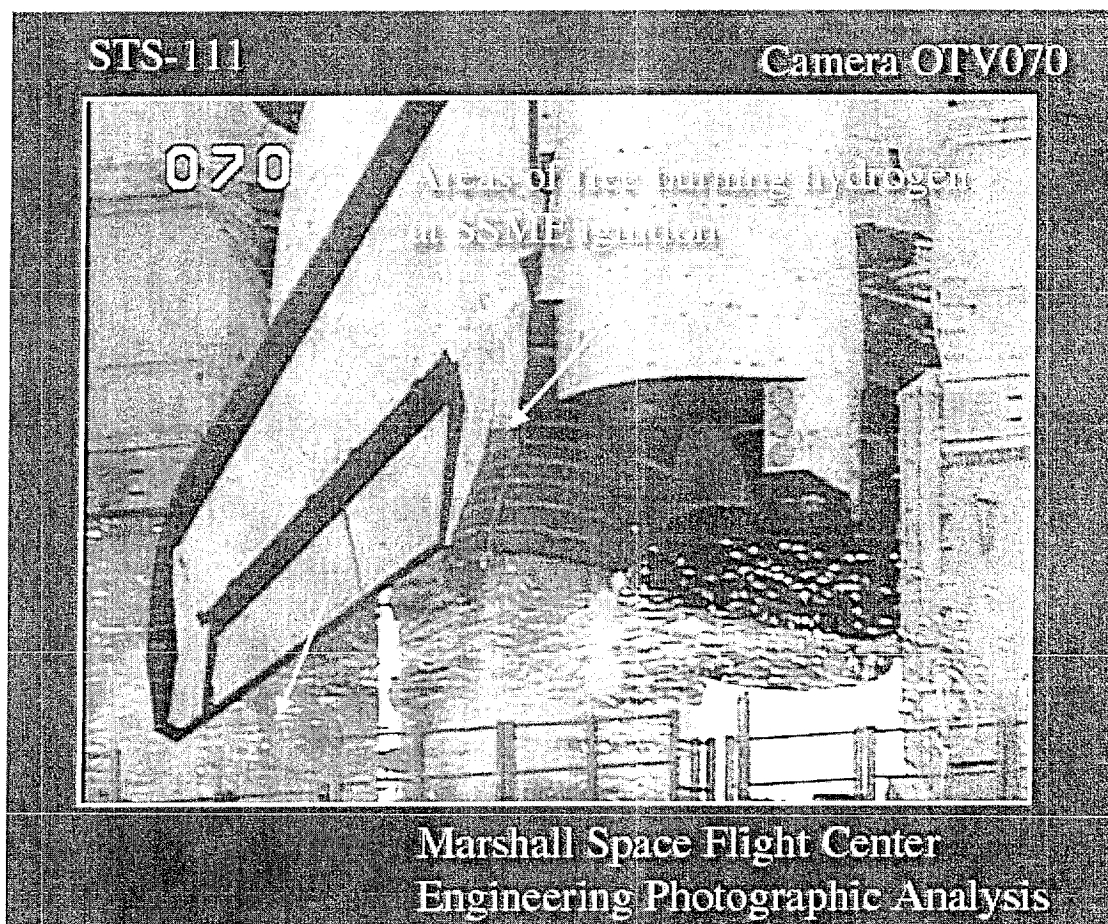


Figure 12. OTV070: Free Burning Hydrogen

Video Camera OTV063: Free Burning Hydrogen

Free burning Hydrogen was observed on the -Z side of the body flap at SSME startup. Free burning Hydrogen has been observed on the -Z side of the body flap on previous missions.

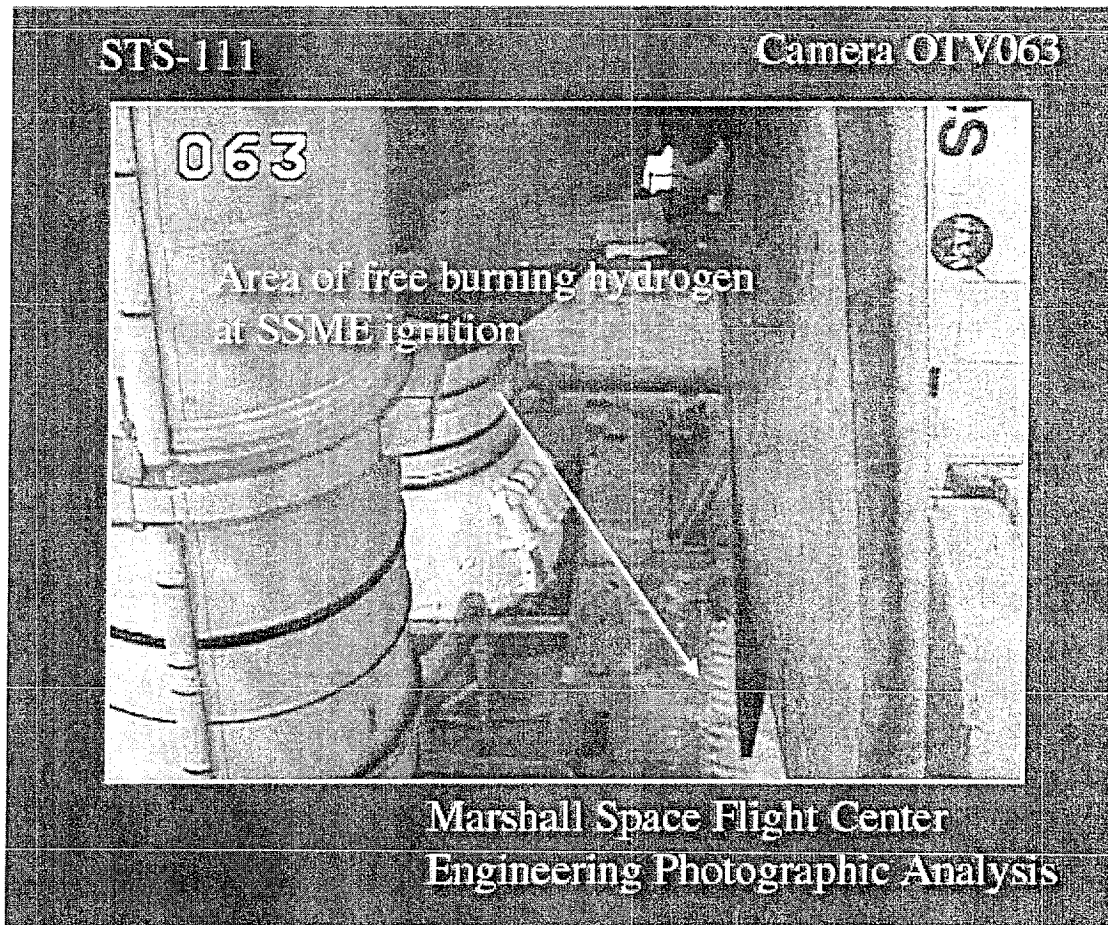


Figure 13. OTV063: Free Burning Hydrogen

Film Camera E4: Ice/Frost on ET/SRB Aft Attach

A light-colored area, indicative of ice or frost, at the EB-7 ET/SRB Aft Attach location was observed prior to liftoff.

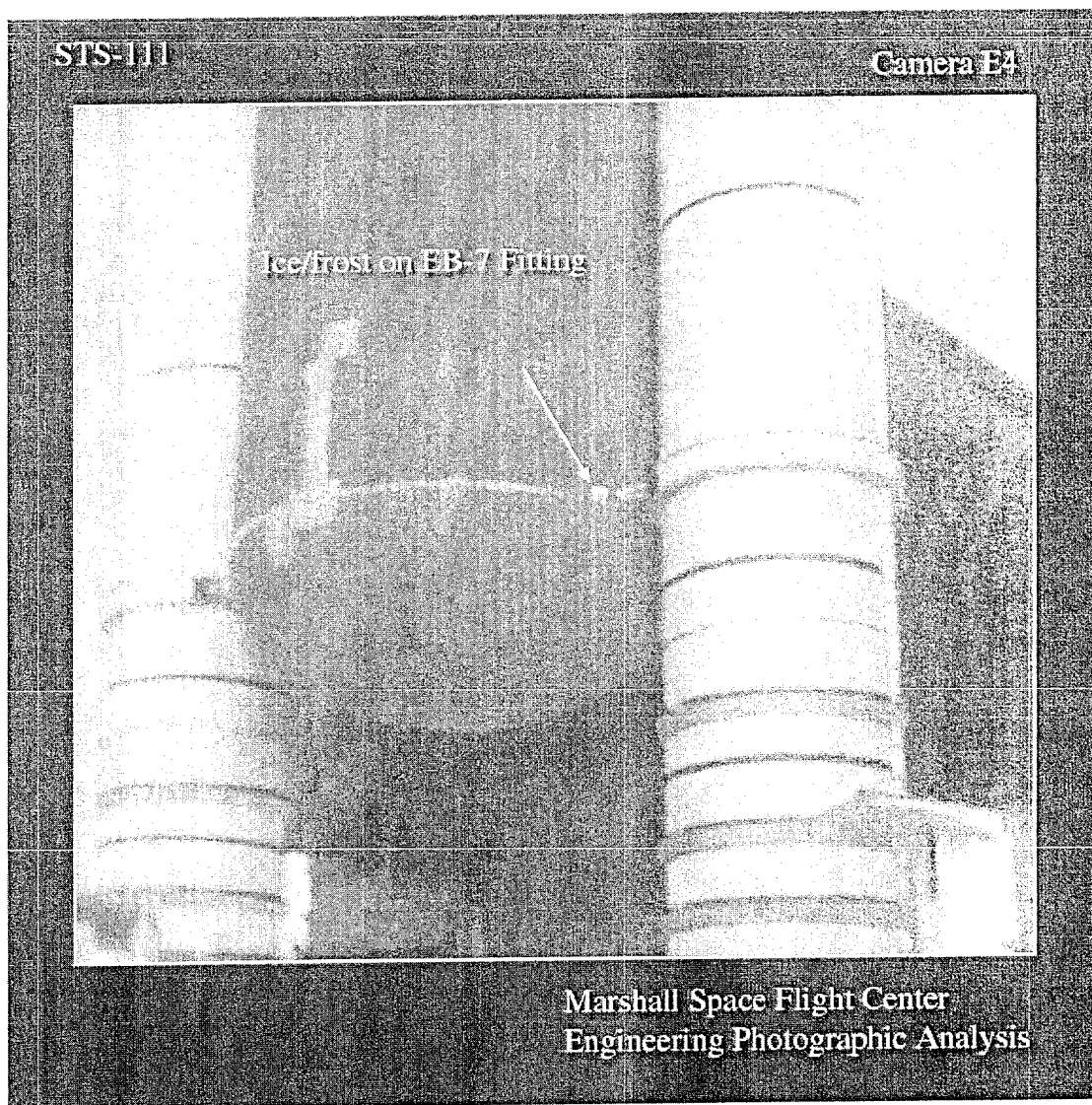


Figure 14. E4: Ice/Frost on ET/SRB Aft Attach

Typical ice/frost was observed falling from the 17-inch disconnects.



Film Camera E18: Debris with White and Black Surface

A debris object was observed forward of the +Y side of SSME#3 nozzle. The debris object was light colored on one side and dark colored on the opposing side, indicative of a chipped Orbiter tile. The images below were obtained between 156:21:22:46.155 and 156:21:22:46.218 UTC.

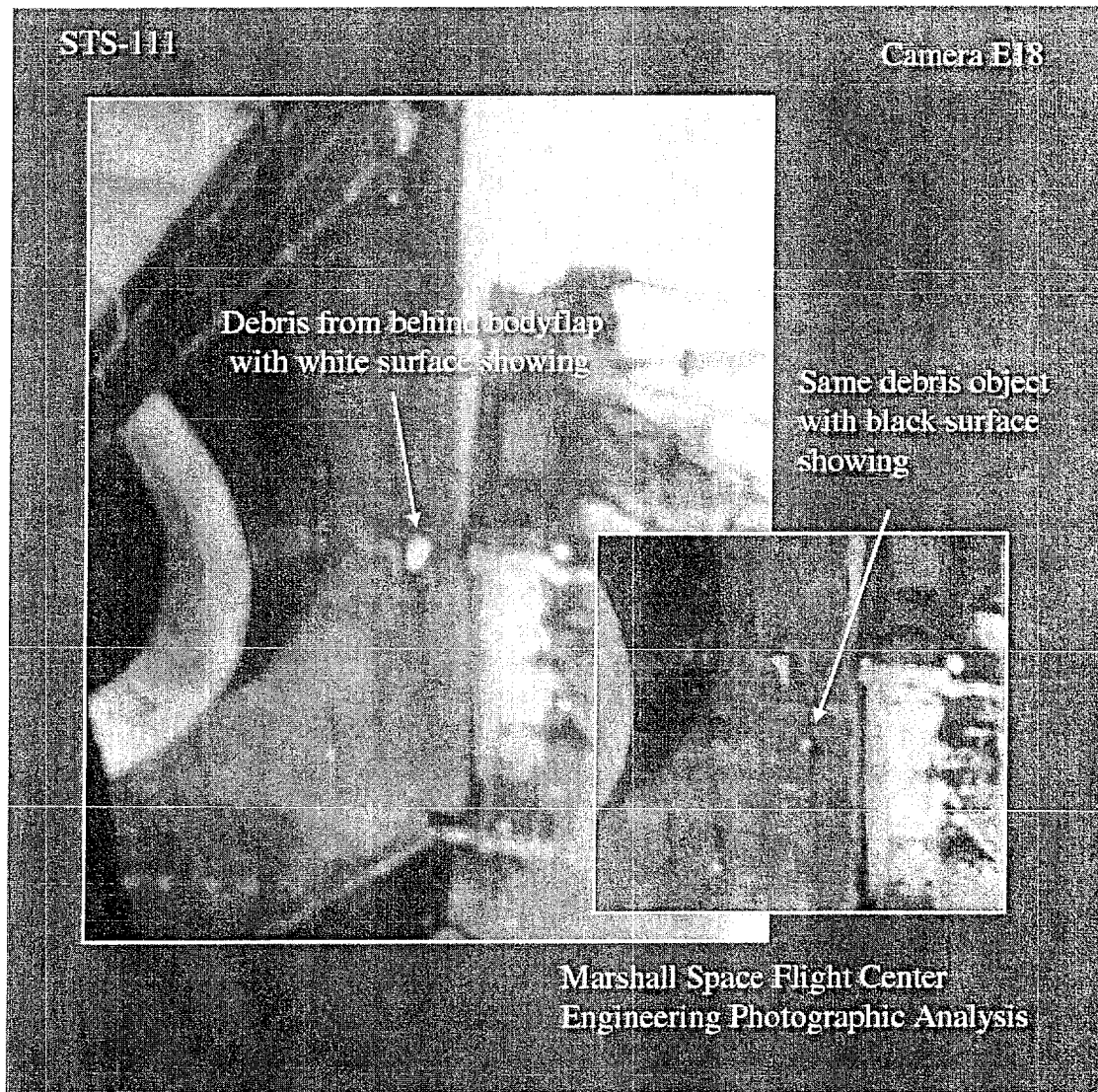


Figure 16. E18: Debris with White and Black Surface

Film Camera E17: T-0 Umbilical Object

A dark object follows the T-0 umbilical toward LO2 Tail Service Mast during umbilical retraction. The object appears connected by wire to the umbilical assembly, but vapors surrounding the object make positive identification of an attached wire difficult. The image below was timed at 156:21:22:49.499 UTC.



Figure 17. E17: T-0 Umbilical Object

Film Camera E10: Blast Deflection Shield Descent

The blast deflection shield for Holddown Post M3 on MLP-1 appeared to take longer than usual to completely descend to a level position, with the shield not completely closed as the nozzle exit plane rises past the Holddown post.

A review of film from camera E10 for the last mission utilizing MLP-1, STS-108, also revealed a similar phenomenon.

This item is listed on the Intercenter Consolidated Film/Video Launch+4 Day Report.

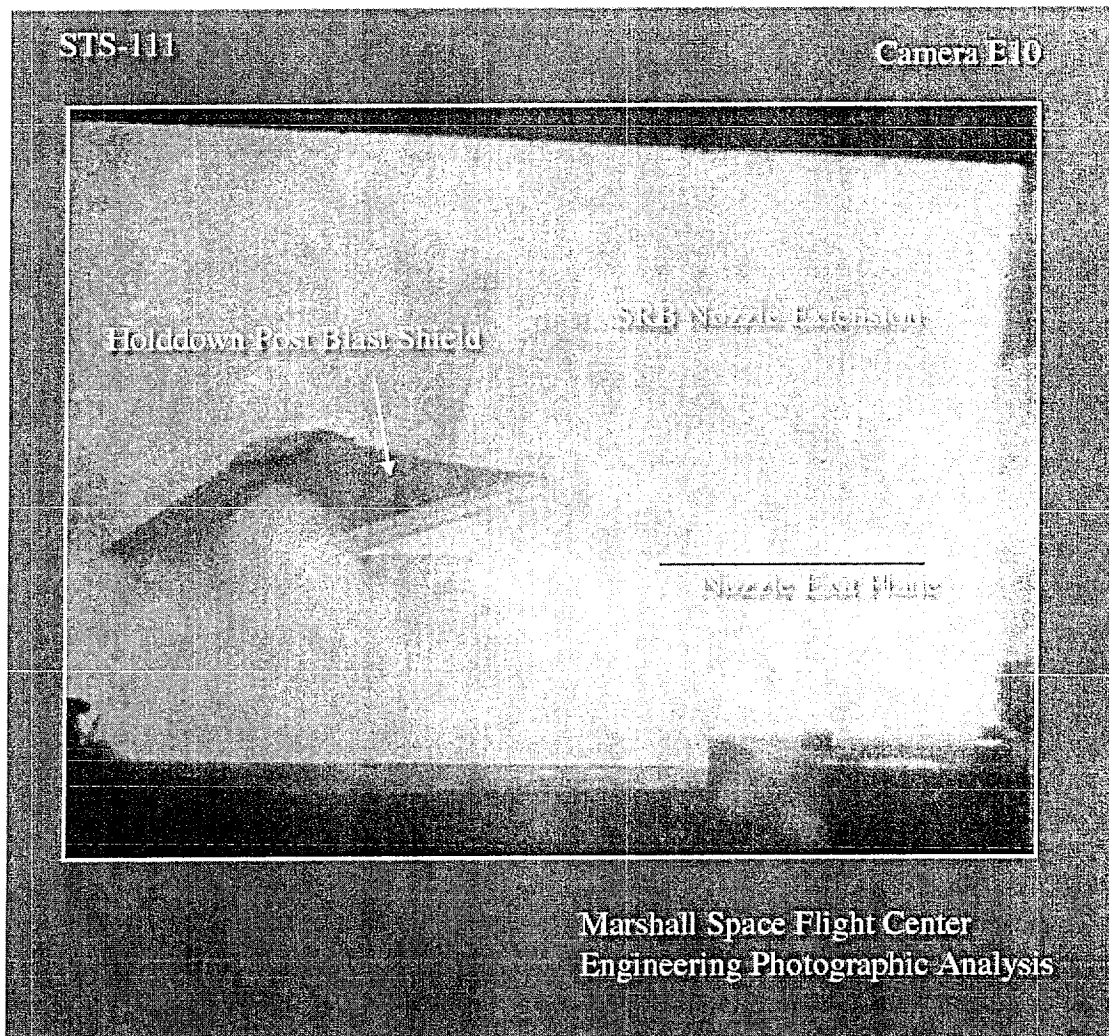


Figure 18. E10: Blast Deflection Shield Descent

Video Camera OTV061: Debris Traveling Toward SRB

A light-colored debris object was observed traveling toward the LSRB just after liftoff.



Figure 19. OTV061: Debris Traveling Toward SRB

Video Camera TV21: Debris-induced Streaks in SSME Plumes

Debris-induced streaks were observed in SSME plumes during ascent.

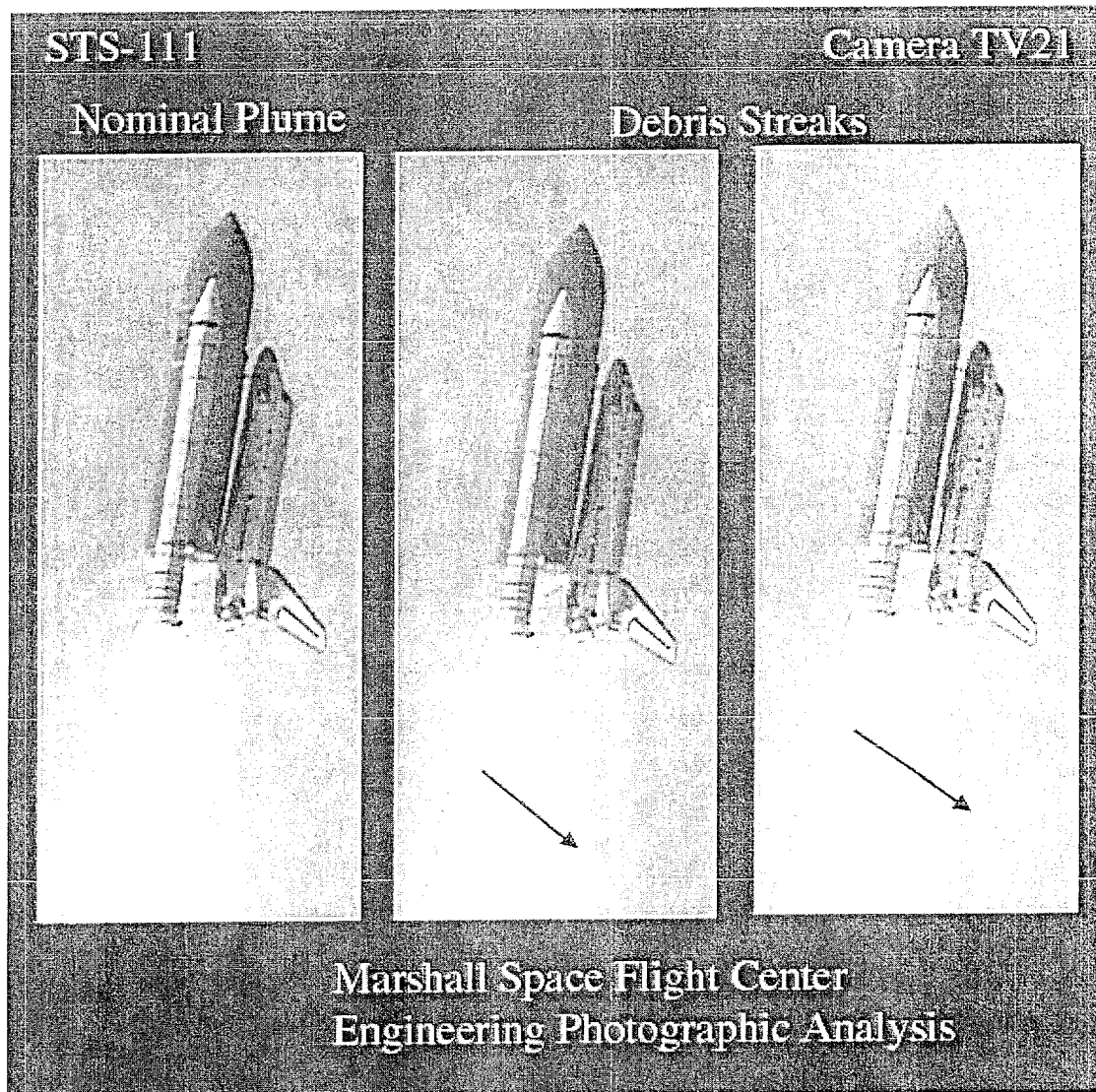


Figure 20. TV21: Debris-induced Streaks in SSME Plumes

Video Camera TV4A: Debris-induced Streaks in SSME Plumes

Debris-induced streaks were observed in SSME plumes during ascent.

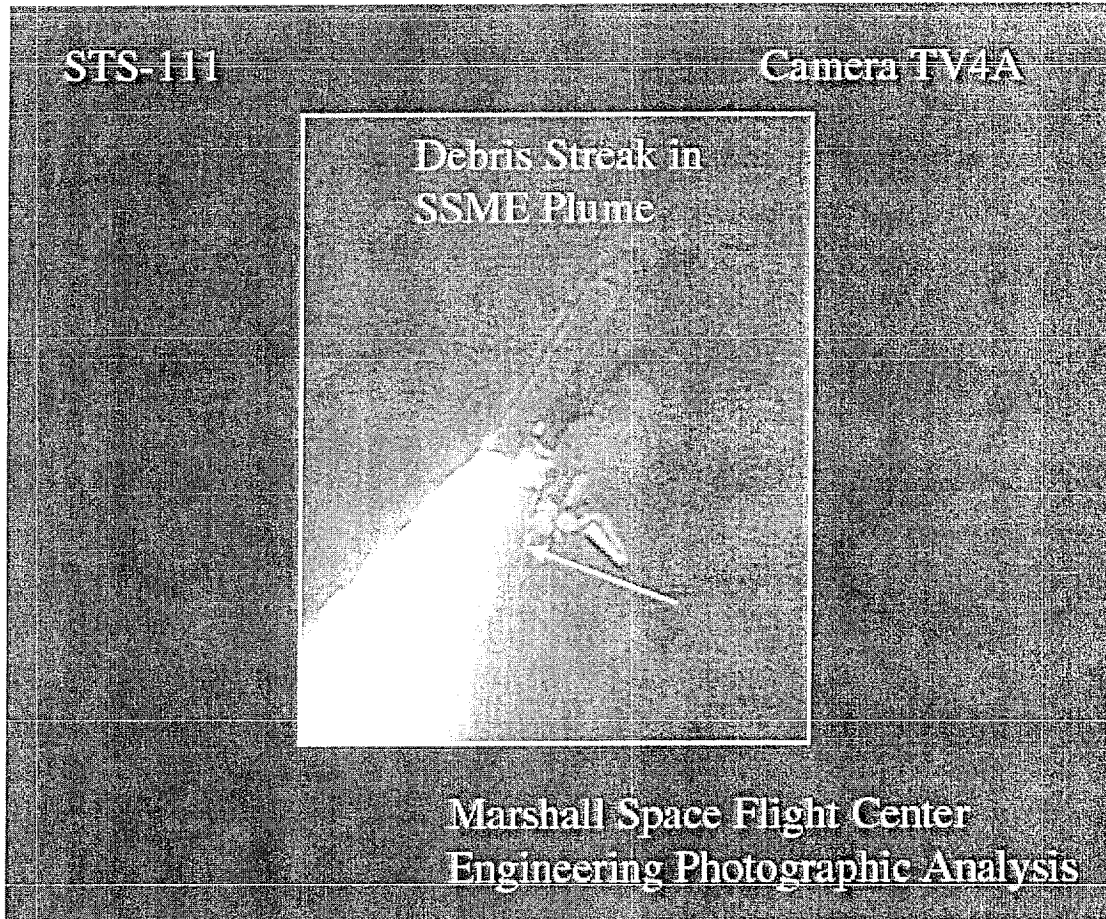


Figure 21. TV4A: Debris-induced Streaks in SSME Plumes

Film Camera E52: Forward RCS Paper Falling Aft

Forward RCS Butcher Paper was observed falling over the left wing of the Orbiter during ascent.

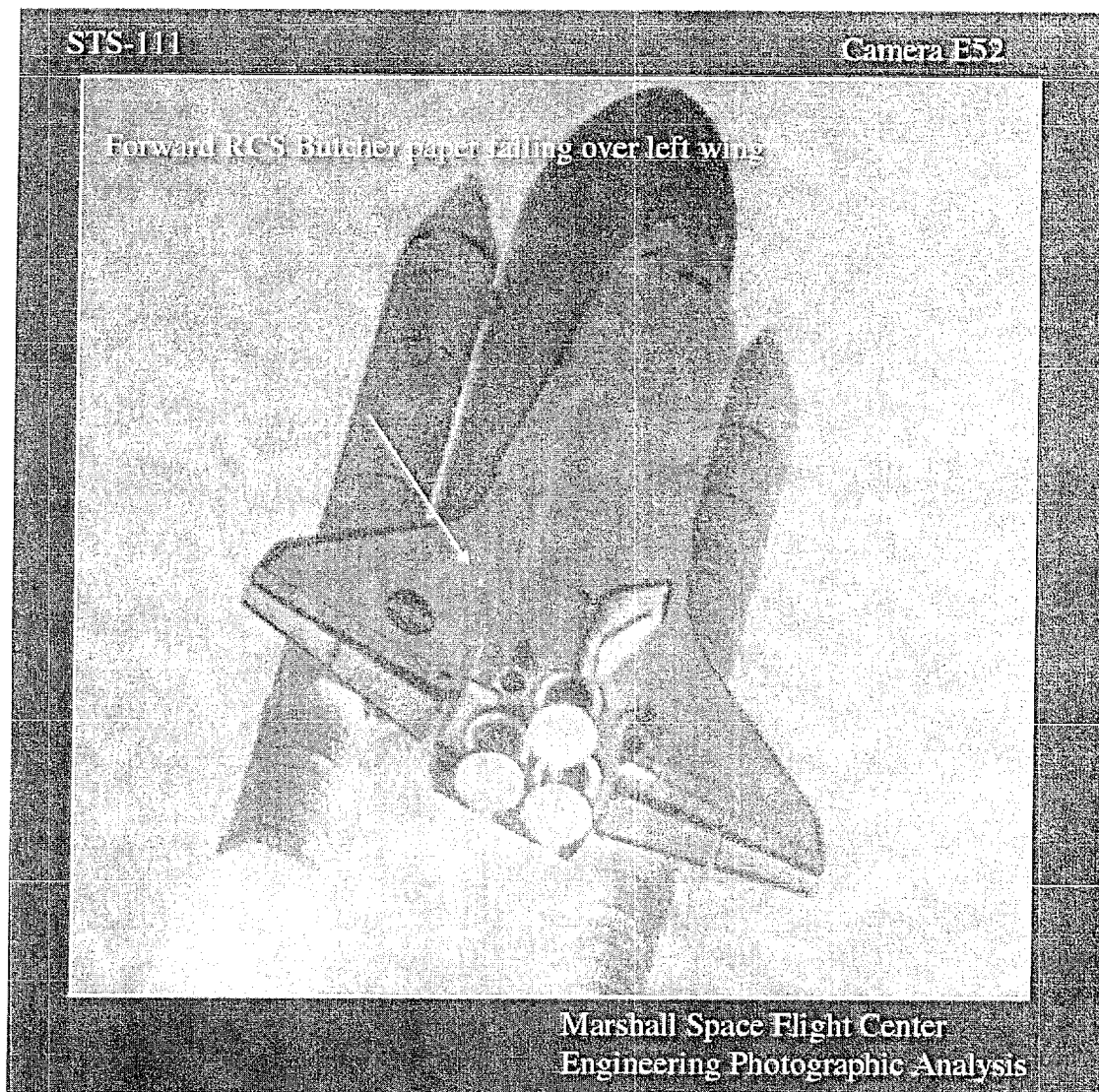


Figure 22. E52: Forward RCS Paper Falling Aft

Film Camera E207: Examples of Debris Falling Aft

Typical sources of debris falling aft of the vehicle during ascent are Purge Barrier Material and Butcher Paper.

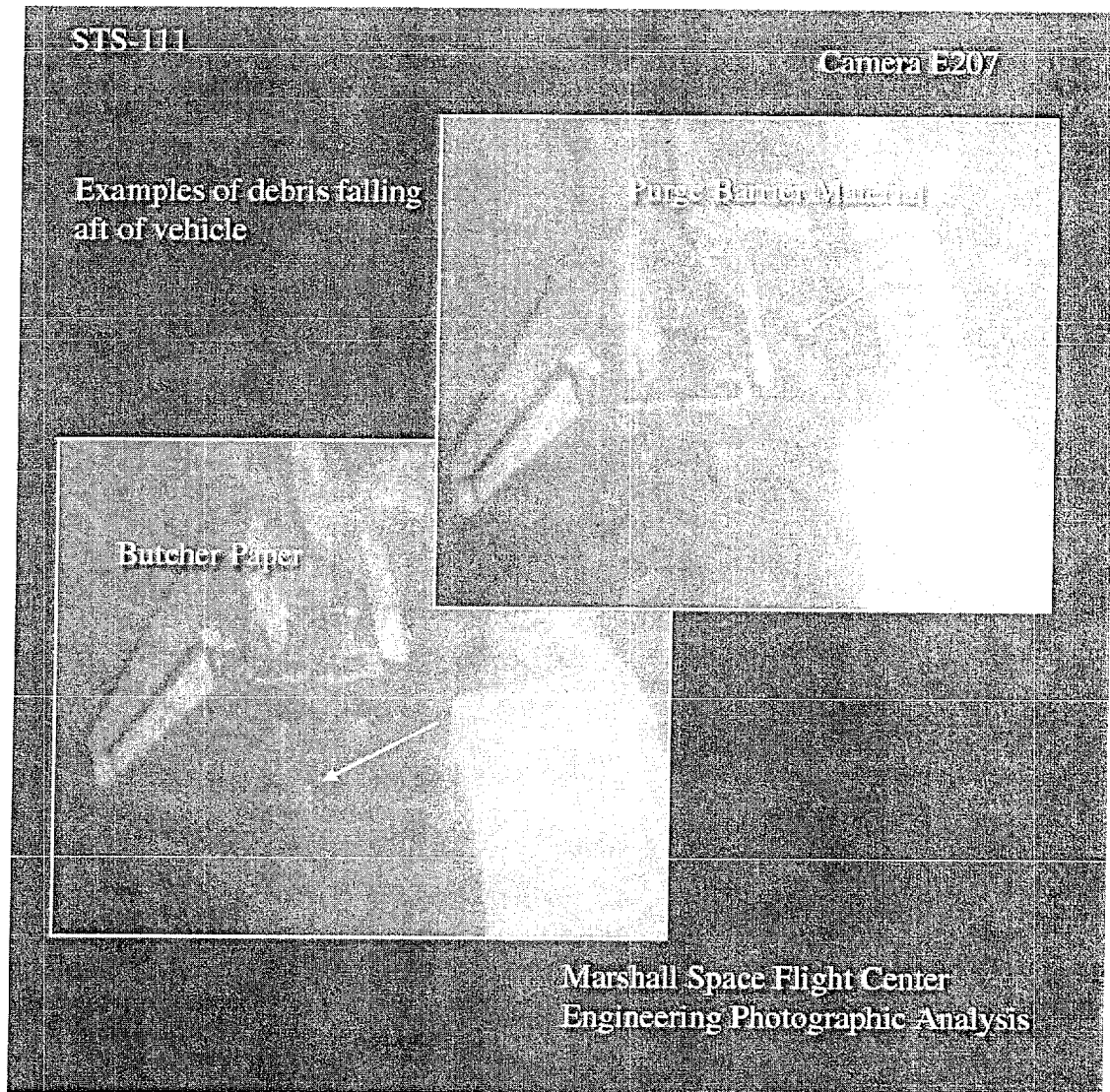


Figure 23. E207: Examples of Debris Falling Aft

Video Camera TV4A: Condensation Cloud

A condensation cloud was observed around the vehicle during ascent.

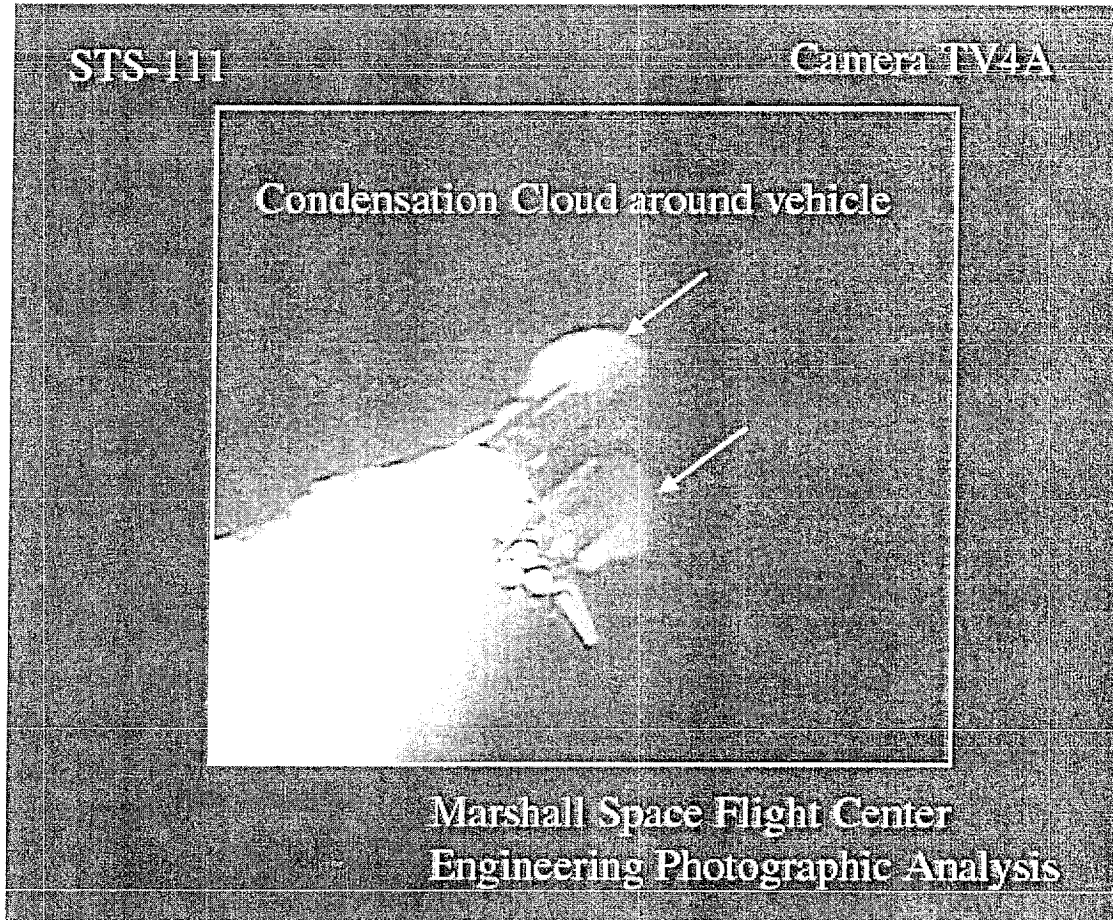


Figure 24. TV4A: Condensation Cloud

Film Camera E224: Condensation Cloud

A condensation cloud was observed around the vehicle during ascent.



Figure 25. E224: Condensation Cloud

Film Camera E207: Nominal Frost on SSME Nozzles

Frost on SSME nozzles appears nominal.



Figure 26. E207: Nominal Frost on SSME Nozzles

Video Camera ET207: Nominal Frost on SSME#3 Nozzle

Frost on SSME#3 nozzle appears nominal.

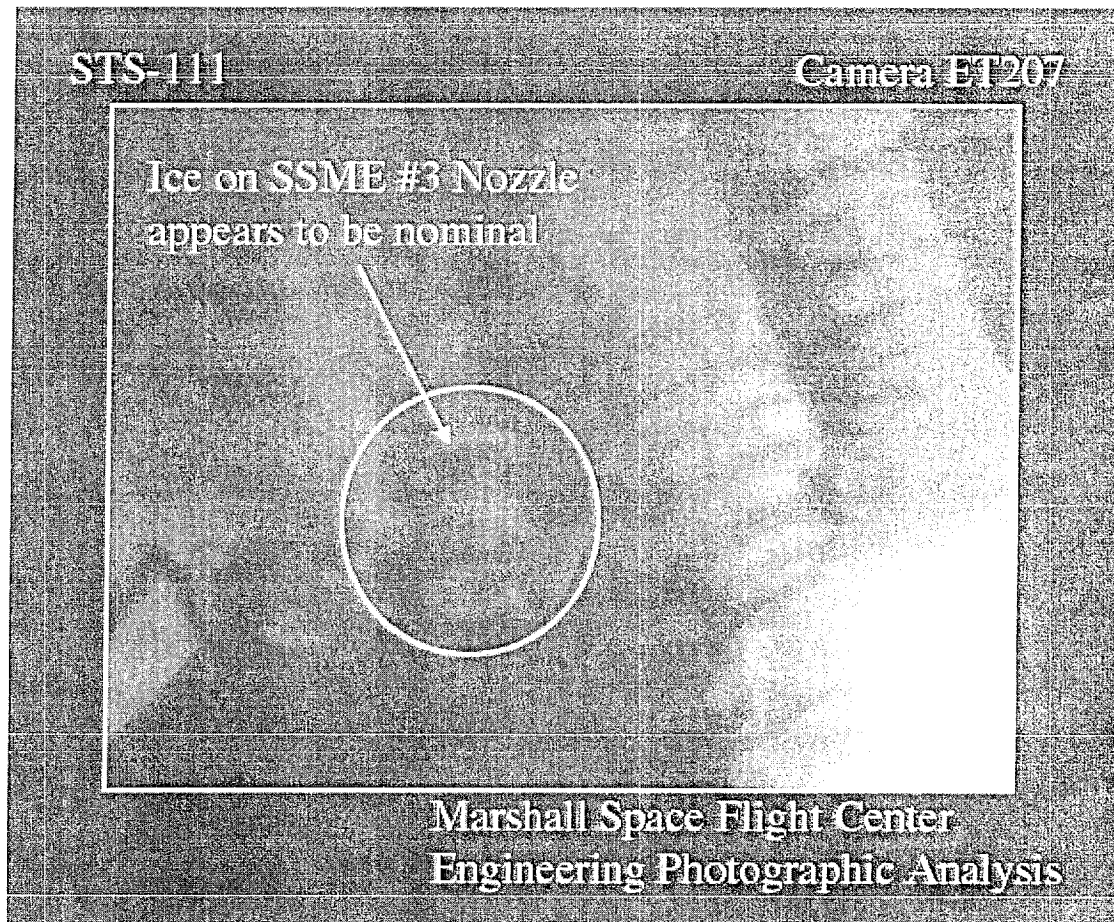


Figure 27. ET207: Nominal Frost on SSME#3 Nozzle

Film Camera E207: Flow Recirculation

Flow recirculation was observed during ascent.



Figure 28. E207: Flow Recirculation

Video Camera ET207: Flow Recirculation

Flow recirculation was observed during ascent.

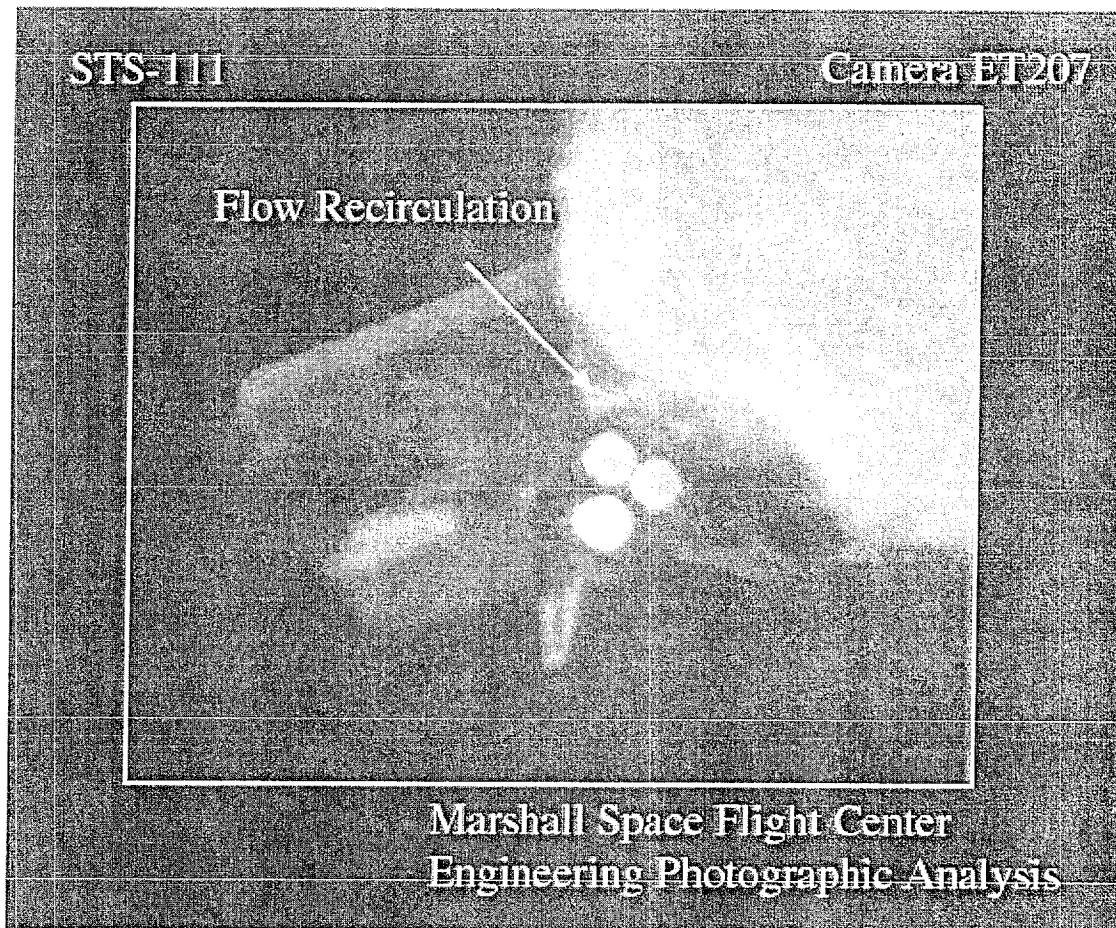


Figure 29. ET207: Flow Recirculation

Film Camera E212: Debris Falling Aft

Debris was observed falling aft of the vehicle during ascent.



Figure 30. E212: Debris Falling Aft

Video Camera ET213: Dark Plume Events

Three separate events in which dark areas appeared in the SRB plumes were observed. The events were timed at 156:21:24:42.348, 156:21:24:42.548, and 156:21:24:42.681 UTC.

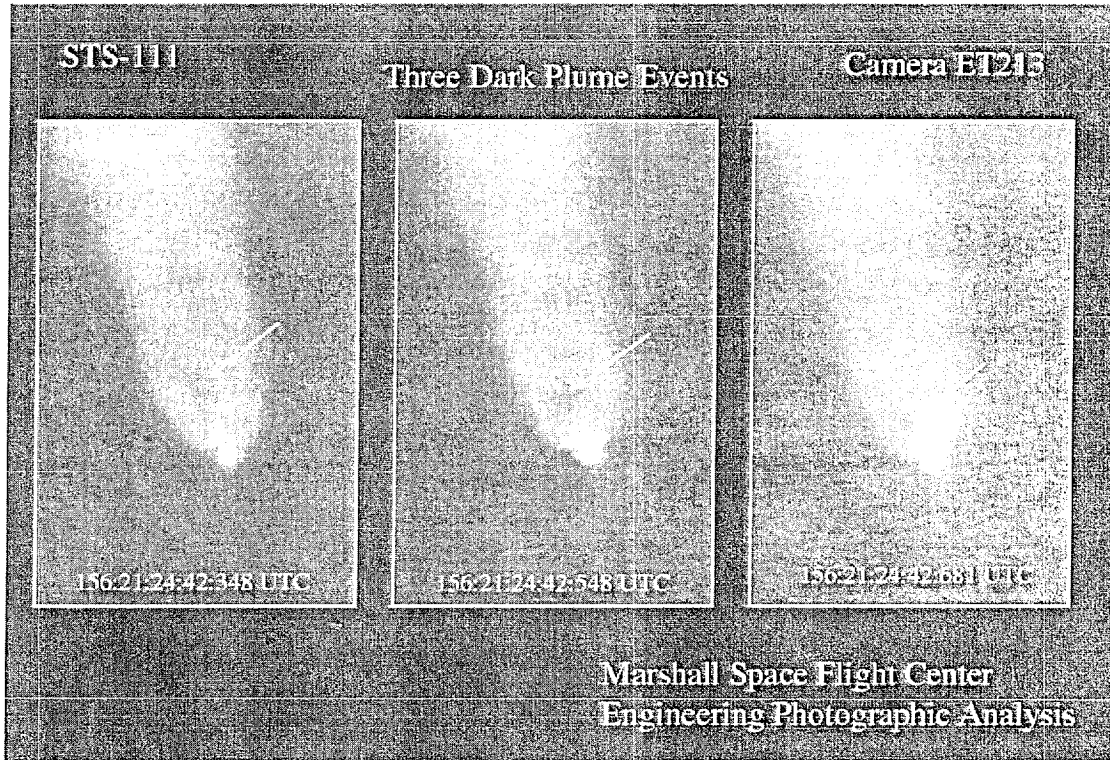


Figure 31. ET213: Dark Plume Events

Video Camera ET207: Dark Plume Event

A closer view of one plume darkening and a comparison to a normal plume in this time frame is shown in Figure 32.

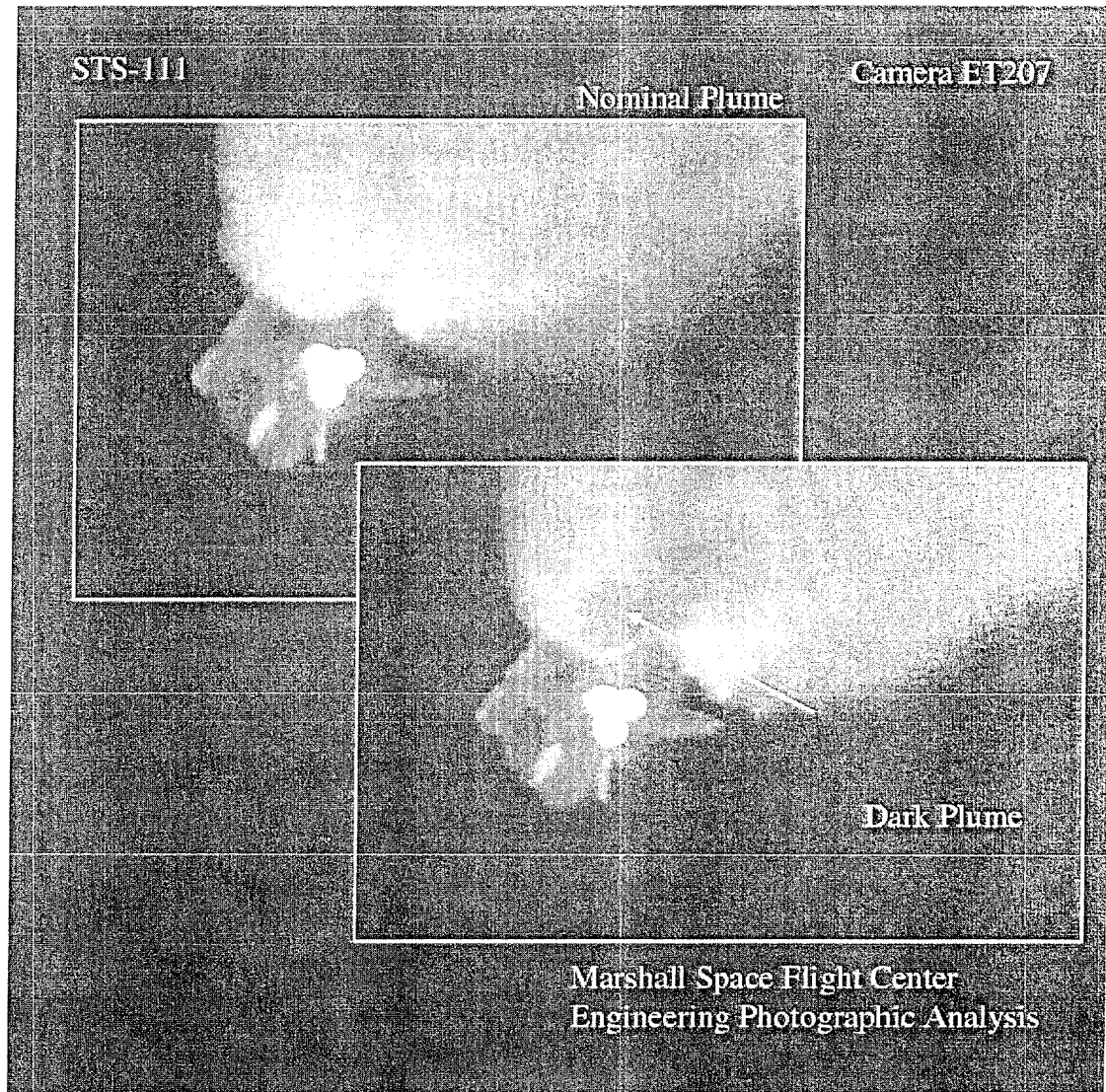


Figure 32. ET207: Dark Plume Event

Astronaut Handheld 35mm Still Camera: External Tank -Z and -Y Side TPS

The condition of the TPS visible on the -Y and -Z side of the External Tank appeared nominal.

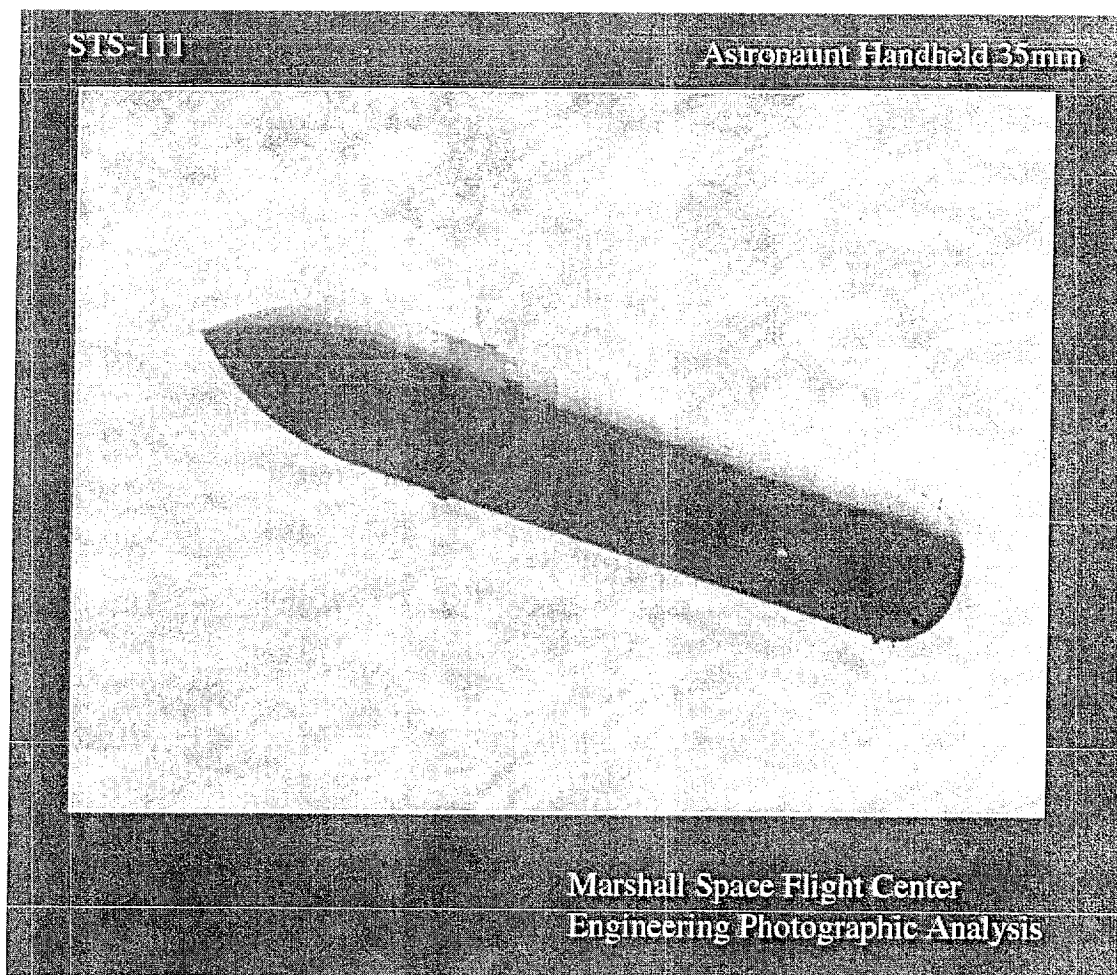


Figure 34. HH35mm: External Tank -Z and -Y Side TPS

Astronaut Handheld 35mm Still Camera: External Tank +Y and +Z Side TPS

The condition of the TPS visible on the +Y and +Z side of the External Tank appeared nominal.

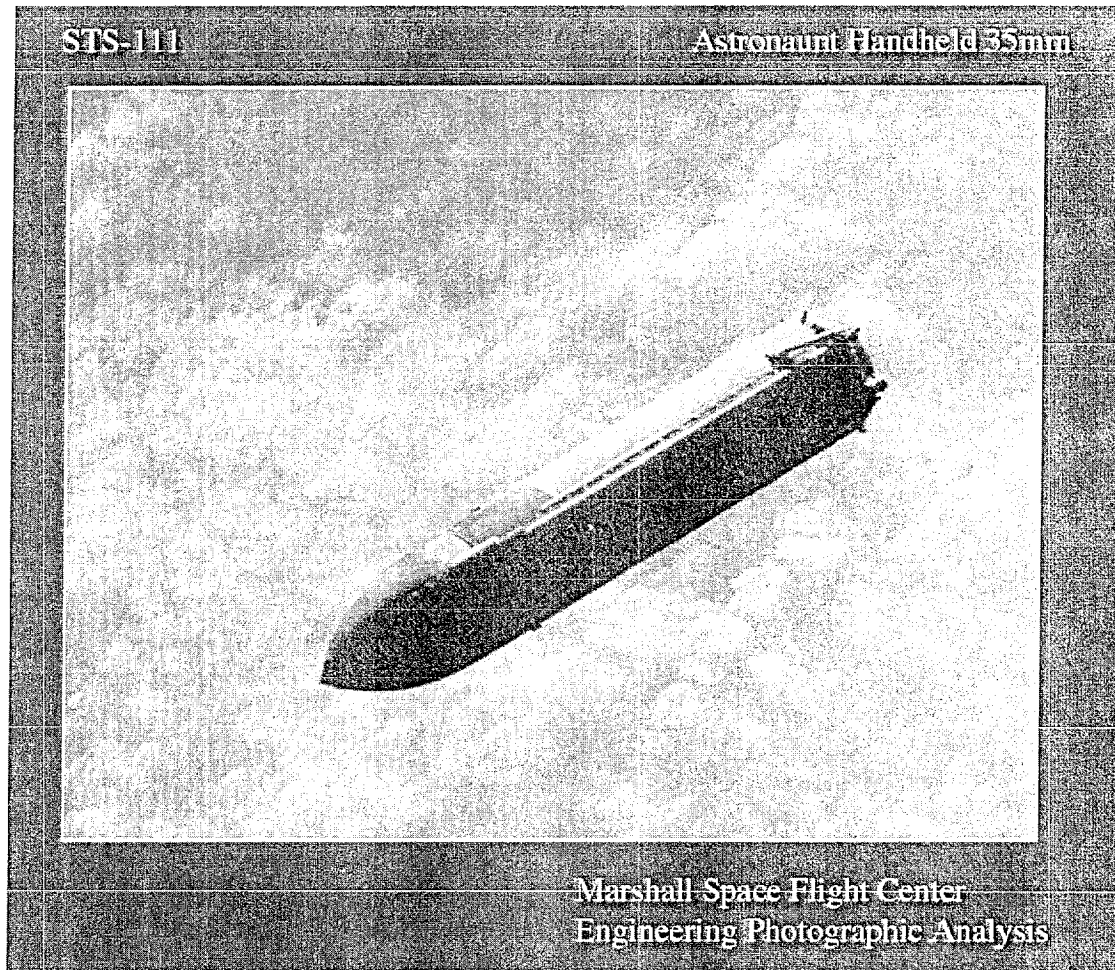


Figure 33. HH35mm: External Tank +Y and +Z Side TPS

Astronaut Handheld 35mm Still Camera: External Tank -Z and -Y Side TPS

The condition of the TPS visible on the +Y and -Z side of the External Tank appeared nominal.

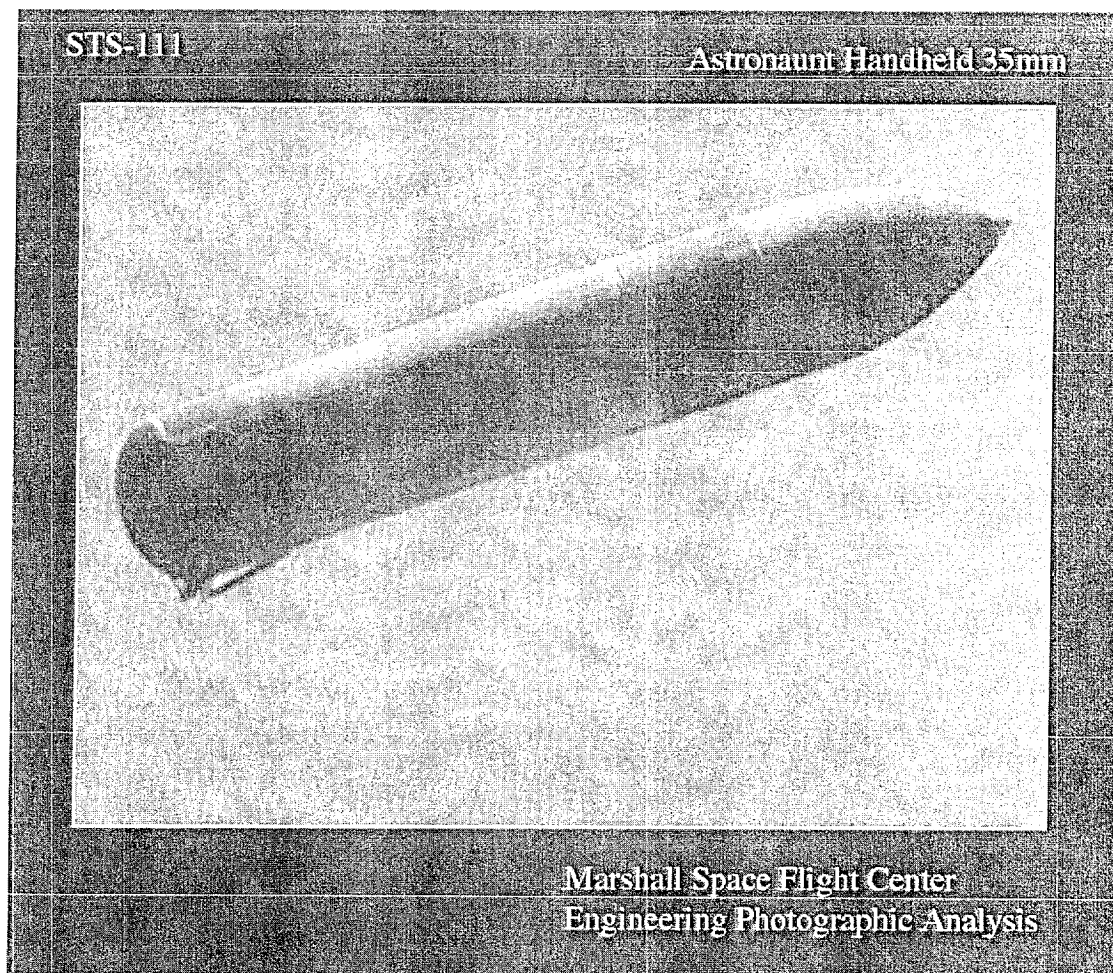


Figure 35. HH35mm: External Tank -Z and -Y Side TPS

Astronaut Handheld 35mm Still Camera: External Tank +Z Side TPS

The condition of the TPS visible on the +Z side of the External Tank appeared nominal.

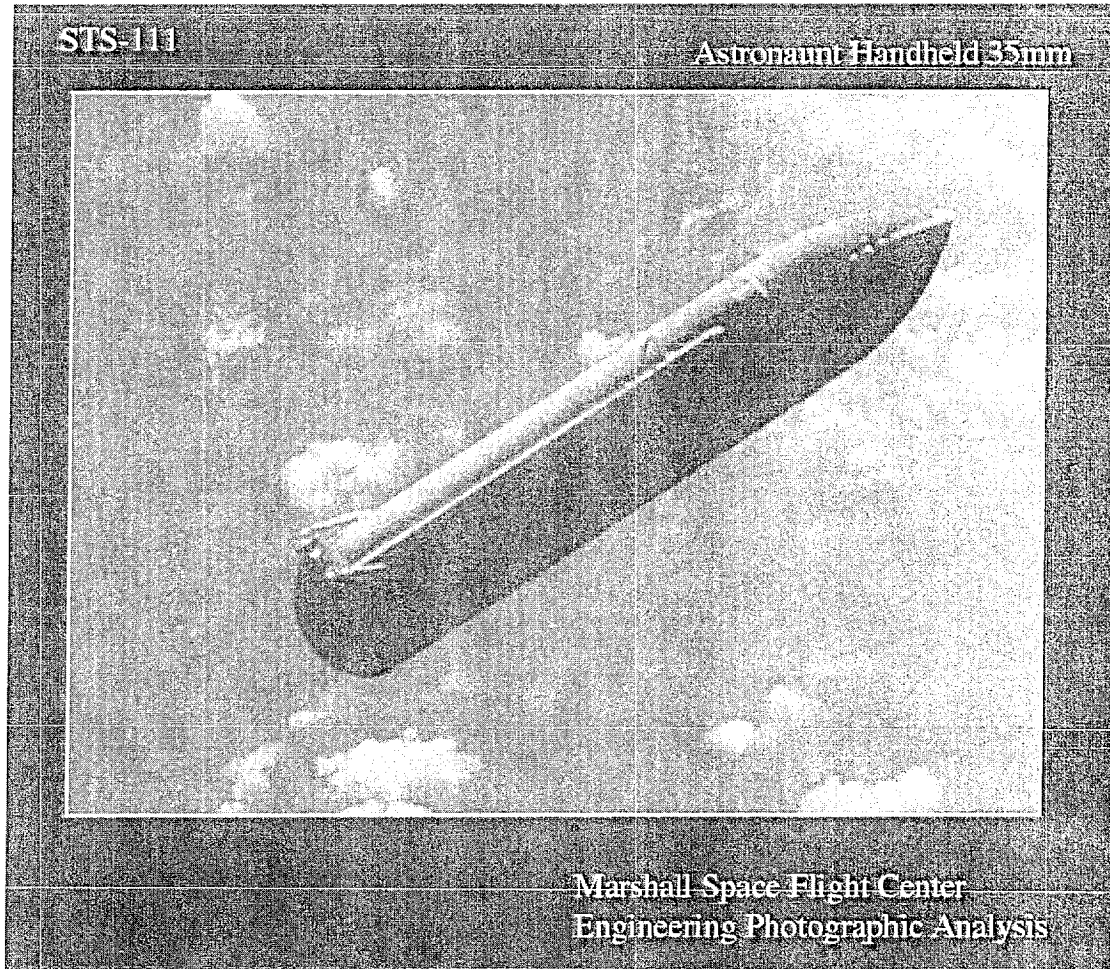


Figure 36. HH35mm: External Tank +Z Side TPS

Astronaut Handheld Video Camera: Venting from GUCP after ET/Orbiter Separation

Venting from GUCP was noted after ET/Orbiter separation. Good examples of this venting are illustrated in Figure 37. Venting from the GUCP has been seen on previous missions.

Although fine details could not be discerned, the general condition of TPS appeared good in imagery from the Astronaut Handheld Video camera.

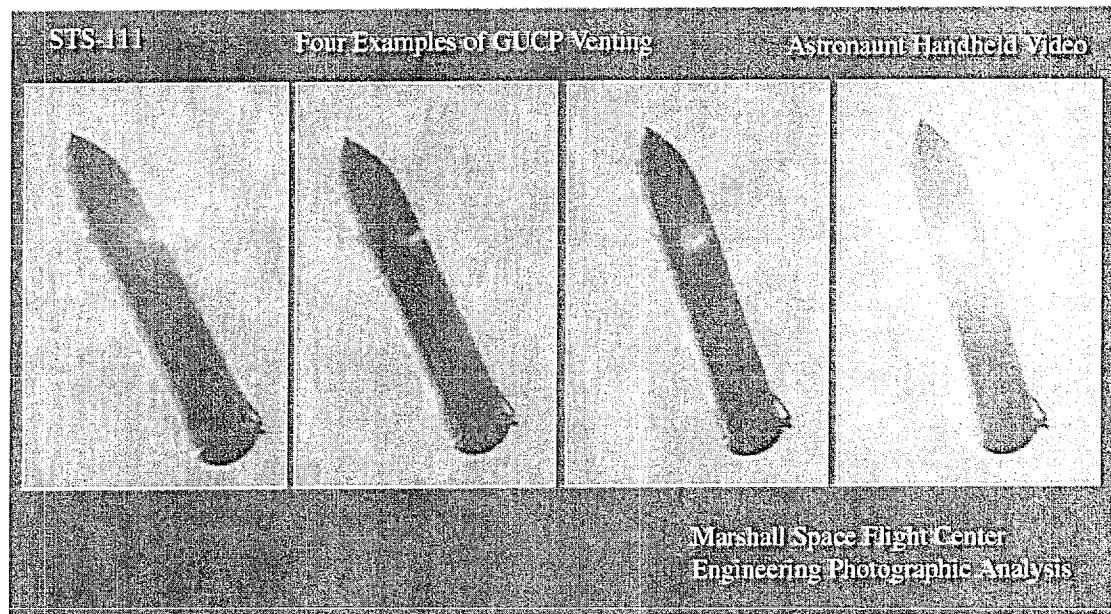


Figure 37. HHVideo: Venting from GUCP after ET/Orbiter Separation

ET Imagery from the Umbilical Well 35mm Still Camera:

TPS loss was typical. Normal popcorning and divoting of the aft dome, Figure 38. Typical TPS missing from thrust strut and LO2 feedline, Figure 38 and Figure 39. Divot noted on thrust strut, Figure 38. Three small divots noted, two under and one on the +Y side, near the bipod, Figure 41. One divot on intertank noted near forward -Y side of the LO2 feedline, Figure 43. Nosecap appeared nominal, Figure 44. The purge seal was noted in place around the EO3 joint, Figure 38. Glare from within EO3 joint bore observed, probably a reflection from the chamfer of EO3 bolt, Figure 38. A small positive yaw angle noted as ET moves away from Orbiter is noticeable through the sequence of frames.

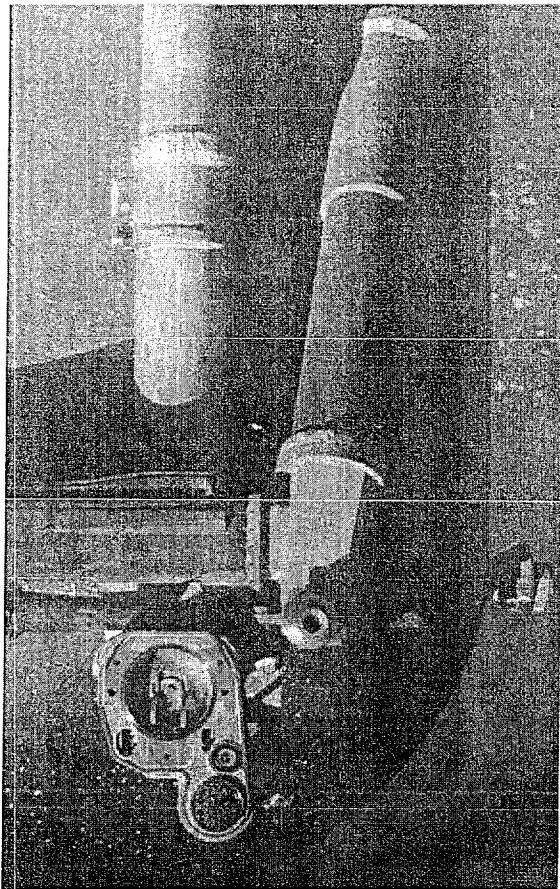


Figure 38. UMB35mm: Frame 12

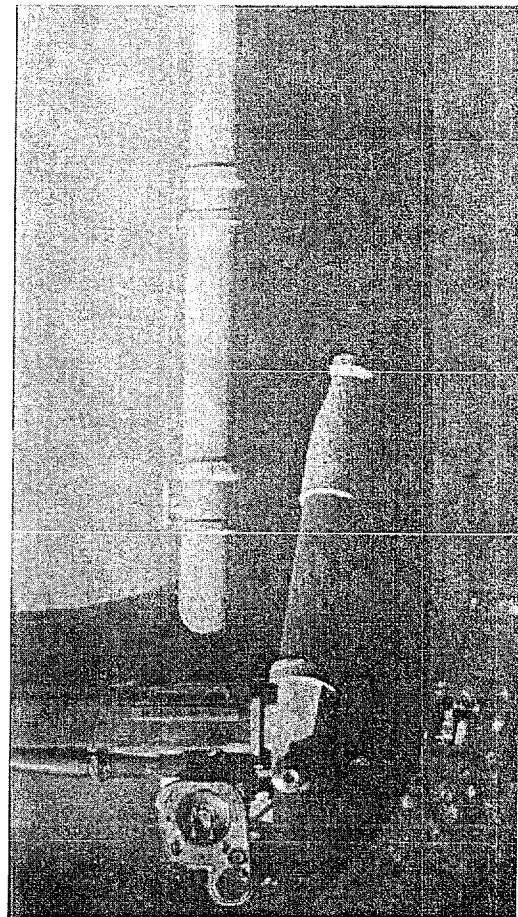


Figure 39 UMB35mm: Frame 20

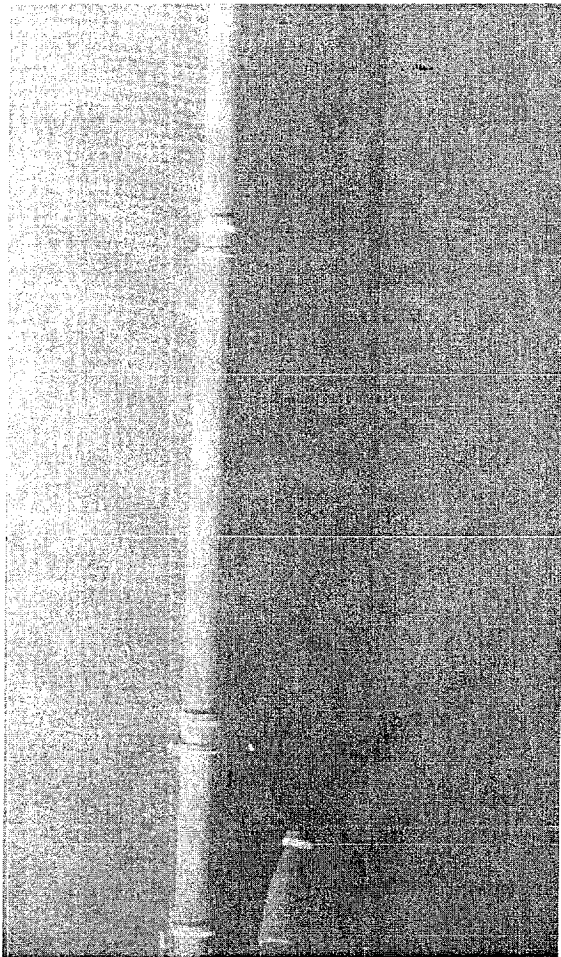


Figure 40 UMB35mm: Frame 30

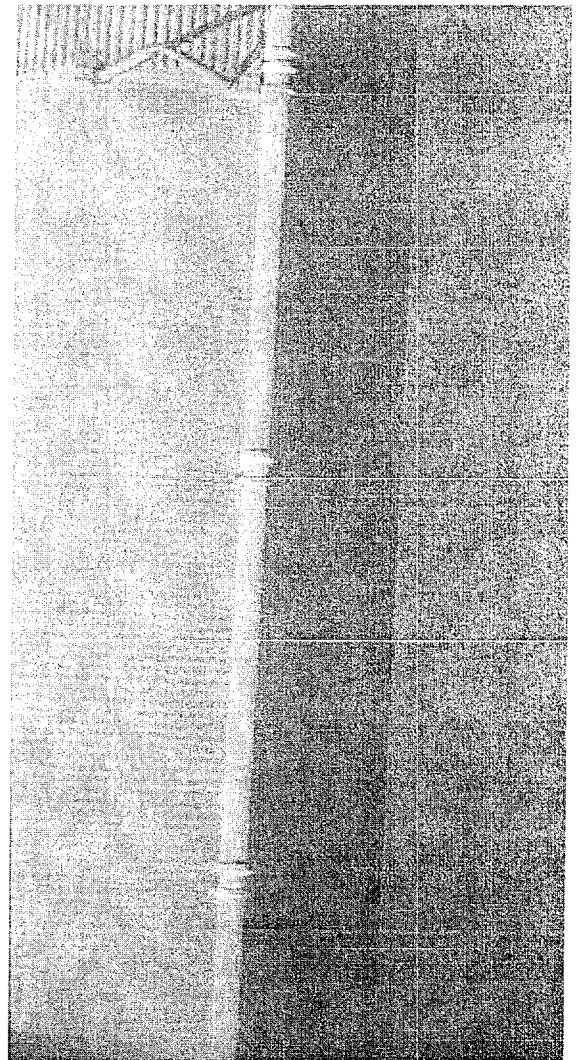


Figure 41 UMB35mm: Frame 40

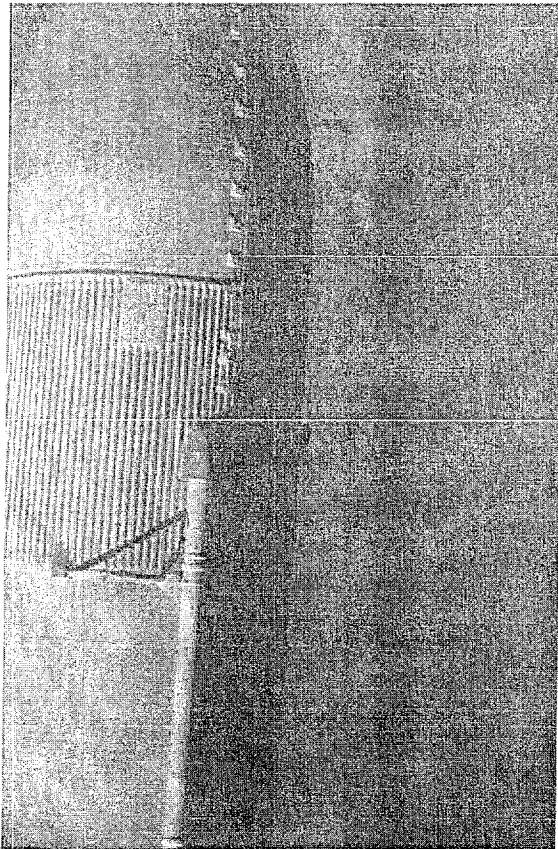


Figure 42 UMB35mm: Frame 49

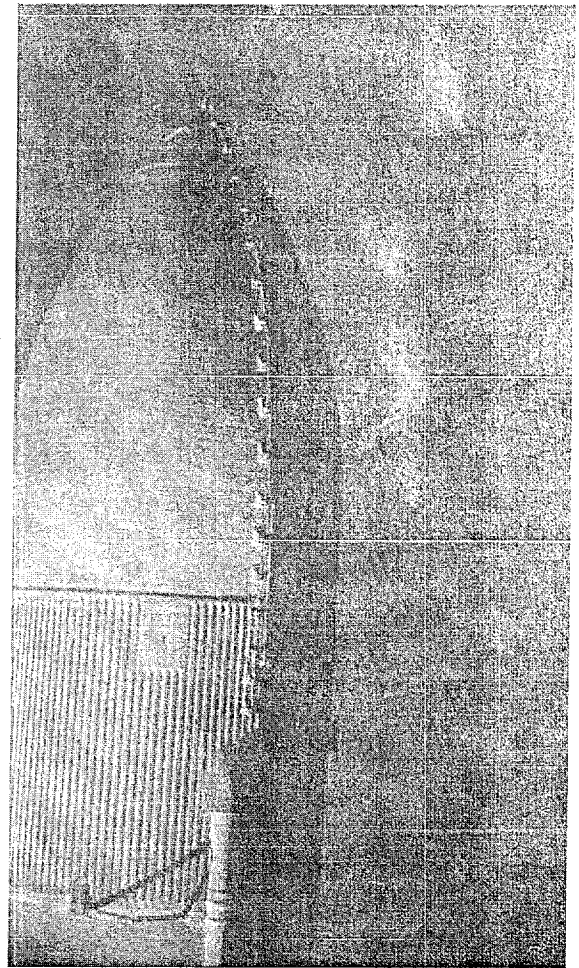


Figure 43 UMB35mm: Frame 54

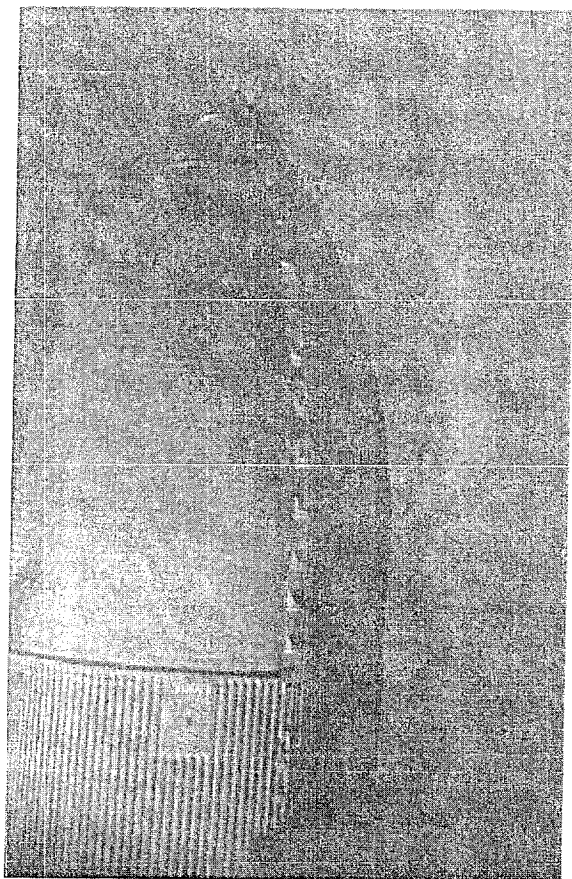


Figure 44 UMB35mm: Frame 58

Individual Camera Assessments:

Assessments for individual cameras are listed below. The assessments for all individual cameras including camera characteristics as noted in the Photographic Acquisition Disposition Document (PADD) for flight STS-111 may also be found on the website.

Video Camera Assessments

| | |
|---------|---|
| TV13 | Linear optical distortions noted. Camera occasionally loses focus. |
| TV4A | Debris-induced streak observed in SSME plume. SRB separation: 156:21:24:52.9 UTC. Red-colored flash noted near SSME plumes prior to liftoff. Condensation vapors noted surrounding vehicle during ascent. Light colored debris ejected from SRB plumes during ascent at 156:21:23:59.595, 156:21:24:00.929, and 156:21:24:04.967 UTC. Dark puffs in SRB plumes noted at 156:21:24:42.271, 156:21:24:42.504, and 156:21:24:42.638 UTC. |
| TV7A | Red-colored flash noted near SSME plumes prior to liftoff. |
| ET204 | Atmospheric haze degrades image quality. |
| ET207 | Glowing debris particles ejected from SRB plume prior to, during and after separation. Linear optical distortions noted. Flow recirculation noted. Body flap motion noted. Condensation cloud surrounding vehicle noted. OMS Assist burn noted after SRB separation. Ice on SSME3 nozzle appears normal. |
| ET208 | Atmospheric haze degrades quality of image. |
| ET212 | Condensation collar noted during ascent. Atmospheric haze degrades image quality. |
| ET213 | SRB separation: 156:21:24:52.9 UTC. Three dark puffs observed in SRB plumes prior to SRB separation. Atmospheric haze degrades image quality. |
| TV21A | Debris-induced streaks observed in SSME plume. A red-colored flash near SSME plumes was visible prior to liftoff. Atmospheric acoustic waves noted as condensation collar forms. |
| OTV009 | Typical ice/frost from 17-inch disconnects. |
| OTV041 | Exposure has high contrast, degrading quality of image. |
| OTV048 | Poor exposure limits engineering use. |
| OTV051 | Mach diamond formation in 3-2-1 order. |
| OTV054 | Typical ice/frost from 17-inch disconnects. Typical wing motion observed. |
| OTV061 | White-colored debris noted near Left SRB. |
| OTV063 | Typical ice/frost from 17-inch disconnects. Small amount of free Hydrogen burning noted on -Z side of the body flap. |
| OTV070 | Free Hydrogen burning noted near the vertical stabilizer and drag chute door. Unusual red-colored puff in SSME plume field noted during SSME ignition at 156:21:22:45.558 UTC. |
| OTV071 | Red-colored flash near SSME plumes noted prior to liftoff. |
| HHVIDEO | Good examples of venting from GUCP observed. Although fine details could not be discerned, the general condition of TPS appeared good. |

Film Camera Assessments

| | |
|----|---|
| E1 | Pad debris noted rising and falling. Typical ice/frost from 17-inch disconnects. Light-colored linear area noted moving aft on -Z side of left SRB just above the Aft Skirt, imaged at 156:21:22:51.131 UTC. |
| E2 | Free burning Hydrogen noted. Large flare in SSME#1 plume prior to mainstage, initiated at 156:21:22:45:535 UTC. |
| E3 | Free burning Hydrogen noted. Reddish-orange flash in SSME#1 plume prior to mainstage, imaged at 21:22:45.538 UTC. |
| E4 | Pad debris noted rising and falling. Ice/frost noted on -Z side of ET at ET/Left SRB attach point, imaged at 21:22:46.191 UTC. Pad debris observed entering SRB blast holes at SRB ignition, imaged at 21:22:50.457 UTC. Light colored linear area, probably a reflection, noted on -Z side of Left SRB near Aft Skirt, imaged at 21:22:51:123 UTC. |

E6 Typical ice/frost from 17-inch disconnects.

E7 Typical pad debris observed.

E8 Holddown Post M2 PIC Firing time at 156:21:22:49.016 UTC. Typical pad debris observed.

E9 Holddown Post M1 PIC Firing at 156:21:22:49.015 UTC. Typical pad debris observed. Camera appears to slow down just after liftoff.

E10 Facility debris noted falling through field of view. Blast deflection shield appeared to protect HDP from SRB plume, image taken.

E11 Typical pad debris.

E12 Holddown Post M5 PIC Firing time at 156:21:22:49.014 UTC. Debris noted coming from DCS, imaged 156:21:22:49.056 UTC. Typical pad debris noted.

E13 Holddown Post M6 PIC Firing time at 156:21:22:49.015 UTC. Particle noted falling from between SRB nozzle and thermal curtain just after liftoff. Typical pad debris observed.

E14 Typical pad debris observed.

E15 Typical pad debris observed. Blast deflection shield on HDP M3 noted to close slightly slower than shield on HDP M4.

E16 Typical ice/frost from 17-inch disconnects. Typical pad debris noted rising and falling.

E17 Typical ice/frost from LO2 T-0 umbilical. Chipped tiles on Orbiter base heat shield noted. Dark object follows T-0 umbilical toward LO2 TSM during umbilical retraction. Object appears connected by wire to GUCP structure, imaged at 156:21:22:49.499 UTC.

E18 Debris observed falling from LH2 TSM. Debris, apparently a piece of Orbiter tile, black on one side and white on the other, noted falling through field of view, imaged at 156:21:22:46.155, 156:21:22:46.193 and 156:21:22:46.218 UTC.

E19 Free burning Hydrogen noted. A reddish-orange flash in the SSME#1 plume prior to mainstage was observed. Mach diamonds formed in 3-2-1 order.

E20 Pad debris noted rising and falling. Typical debris observed falling aft of vehicle. Ice/frost on SSME#2 nozzle bell pre-launch, imaged at 156:21:22:39.179 UTC. Free burning Hydrogen noted, with a late occurring flash in SSME#1 plume starting at 156:21:22:45.538 UTC. This flash appears to initiate from a disturbance within SSME#1 nozzle.

E31 A rather large piece of ice/frost falls from the LH2 recirculation line.

E33 Typical ice/frost noted around GUCP. Ice/frost falling from GUCP observed impacting Left Forward SRB. No damage observed.

E34 Typical debris observed falling aft of vehicle. Ice/frost falling from GUCP observed.

E36 Ice/frost falling from GUCP observed. Typical pad debris observed.

E39 GH2 Vent Arm latching observed.

E40 Typical debris observed falling aft of vehicle.

E54 Vapors from the left wingtip noted just after roll maneuver.

E52 Typical ice/frost from 17-inch disconnects. Late occurring free burning Hydrogen flash observed and imaged. Forward butcher paper falling aft over left wing observed. Debris falling aft over right wing observed.

E57 Pad debris noted rising and falling. Typical debris observed falling aft of vehicle. Debris with smoke/vapor trail on +Z side of Right SRB observed.

E59 Typical debris observed falling aft of vehicle. Debris-induced streaks were observed in SSME plumes.

E60 Typical ice/frost from 17-inch disconnects noted.

E61 GH2 Vent Arm successfully latches.

E62 Free burning Hydrogen observed. Flash in SSME#1 plume prior to mainstage.

E63 Typical debris observed falling aft of vehicle. Flash in SSME#1 plume prior to mainstage.

E64 GH2 Vent Arm retraction appears normal.

E204 Glowing debris particles ejected from SRB plume after separation. Atmospheric haze degrades image quality. Foreign objects in camera obscure part of image. Condensation collar observed. Forward RCS motor firing at SRB separation noted.

E205 Debris-induced streaks observed in SSME plumes. Flow recirculation noted. SRB separation: 156:21:24:52.909 UTC. Condensation collar observed. Three dark puffs noted in SRB plumes prior to SRB separation. Timing display is occasionally incorrect.

E207 Typical debris observed falling aft of vehicle. Debris-induced streaks in SSME plume. Linear optical distortions noted. Flow recirculation noted. SRB separation: 156:21:24:52.901 UTC.

- Debris ejected from SRB plumes during ascent at 156:21:24:46.960 UTC. Debris objects noted flowing over left wing during time period between 156:21:24:49.286 and 156:21:24:49.467 UTC. Forward RCS motor firing observed at SRB separation. Glowing debris particles (slag) ejected from SRB plumes prior to and after SRB separation. OMS motor firing noted at approximately 156:21:25:03 UTC. Three dark puffs noted in SRB plumes prior to SRB separation.
- E208 Atmospheric haze substantially degrades image quality.
- E212 Atmospheric haze degrades image quality early in ascent. Condensation collar around vehicle observed. Dark puffs noted in SRB plumes prior to SRB separation. Debris ejected from SRB plumes prior to SRB separation was imaged. Forward RCS motor firing during SRB separation observed. OMS motor firing after SRB separation observed.
- E213 Debris-induced streaks in SSME plume. Atmospheric haze degrades image quality. Condensation collar around vehicle noted.
- E220 Debris-induced streaks in SSME plume. SRB separation: 156:21:24:52.907 UTC. Atmospheric haze degrades image quality early in ascent. Condensation collar begins to form around forward SRB areas at approximately 156:21:23:30 UTC. Debris ejected from SRB plume during ascent.
- E222 Debris-induced streaks noted, one streak imaged at 156:21:23:21.736 UTC. Condensation collar around vehicle observed.
- E223 SRB separation: 156:21:24:52.907 UTC. Typical debris falling aft of vehicle, imaged at 156:21:23:04.463 UTC. Purge barrier material debris falling past body flap, imaged at 156:21:23:04.736 UTC. Atmospheric haze and clouds occasionally degrade image quality. Several debris-induced streaks observed, one imaged at 156:21:23:21.730 UTC. Another debris-induced streak timed at 156:21:23:23.056 UTC. Condensation collar around vehicle observed, imaged at 156:21:23:33.267 UTC. Debris ejected from SRB plumes during ascent.
- E224 Typical debris observed falling aft of vehicle. Debris-induced streak noted in SSME plume. Camera loses track of vehicle in clouds.
- FL101 General condition of TPS is good. Twang observed on SRB part of EB9 interface at SRB/ET upper aft stabilization strut at SRB/ET separation. Typical strut and cable tray TPS erosion observed. Typical popcorning and charring of ET aft dome. EO2 purge seal noted in place. EO2 bolt was not visible in bore of EO2 joint interface. Positive yaw angle noted between ET and Orbiter. Burn scar on -Y side of ET appears normal. Typical charring and ablation on forward ogive.
- FL102 Twang observed on SRB part of EB9 interface at SRB/ET upper aft stabilization strut at SRB/ET separation. Typical strut TPS erosion observed. Typical popcorning and charring of ET aft dome. EO2 purge seal noted in place. EO2 bolt was not visible in bore of EO2 joint interface. Positive yaw angle noted between ET and Orbiter. Burn scar on -Y side of ET appears normal. Typical ablation on forward ogive.
- HH35mm Typical burn scars on +Y and -Y sides of ET. No obvious divoting of TPS on thrust panels. Other TPS acreage looks good. Nosecap and forward ogive appear normal.
- UMB35mm TPS loss was typical. Normal popcorning and divoting of the aft dome. Typical TPS missing from thrust strut and LO2 feedline. Divot noted on thrust strut. Three small divots noted, two under and one on the +Y side, near the bipod. One divot on intertank noted near forward -Y side of the LO2 feedline. Nosecap appeared nominal. The purge seal was noted in place around the EO3 joint. Glare from within EO3 joint bore observed, probably a reflection from the chamfer of EO3 bolt. Positive yaw angle noted as ET moves away from Orbiter.

For further information concerning this report contact Tom Rieckhoff/TD53 at 256-544-7677 or Michael O'Farrell at 256-544-2620.

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